Invading Nature
Springer Series in Invasion Ecology 16

Matej David
Stephan Gollasch *Editors*

Global Maritime Transport and Ballast Water Management

Issues and Solutions

Second Edition

Springer

Volume 16

Invading Nature - Springer Series in Invasion Ecology

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Global Maritime Transport and Ballast Water Management
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2nd ed. 2024

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ISSN 1874-7809 e-ISSN 2543-0483
Invading Nature - Springer Series in Invasion Ecology
ISBN 978-3-031-48192-5 e-ISBN 978-3-031-48193-2
https://doi.org/10.1007/978-3-031-48193-2

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The registered company address is: Gewerbestrasse 11, 6330 Cham, Switzerland

Foreword

When the International Convention for the Control and Management of Ships' Ballast Water and Sediment (BWM Convention) was adopted in 2004 after more than 10 years of negotiations, it was described as "aspirational". The BWM Convention was based on the scientific knowledge of aquatic species introductions at the time, the political will of countries negatively affected by invasive species introduced by ballast water discharge, and a trust that maritime engineering and technology could provide a solution that could be applied to international shipping. That maritime triumvirate of science, politics, and technology played out in the years between 2004 and 2017, when BWM Convention came into force on 8th September of the latter year.

The role and support that the International Maritime Organization (IMO) played (and continues to play) in facilitating the discussion of those disparate groups is to be commended. Building capacity and training, especially in developing countries, through the GloBallast programme, has been very effective. With the entry into force of the BWM Convention a review of the programme was undertaken, and the materials updated. The GloBallast programme is now completed. However, IMO's Integrated Technical Cooperation Programme continues to offer workshops using materials developed by GloBallast.

As first proposed to IMO in the early 1990s by Canada, based on measures to decrease the number of introduced species being deposited into the Great Lakes from the discharge of ballast water, ballast water exchange was found to be very effective, especially for preventing species introductions between freshwater ports. By undertaking exchange on the high seas, freshwater organisms were flushed out to be replaced by marine organisms not likely

to survive in a freshwater receiving environment. Additionally, differences in salinity between fresh and marine environments ensured that any freshwater organisms still in the ballast water tanks were unlikely to survive. Ballast water exchange was scientifically defendable and politically easy to accept, and the technology was well within the ability of shipbuilders, classification societies, and mariners to undertake (once the safety issues were dealt with). It was quickly implemented in IMO Guidelines. Alas, scientifically it turned out to not be the permanent panacea for species transfers between ports, though the Guidelines for designation of areas for ballast water exchange G14 remain in place until the D-2 standard is phased in (by 8th September 2024 all ships must meet the D-2 standard).

Technology to treat ballast water that would kill or ensure organisms could not reproduce was deemed the long-term solution. Since in many cases that would potentially mean killing organisms with a variety of biocides/active substances that could have negative environmental consequences if discharged, as part of the United Nations family, IMO was able to tap into the expertise of the UN. A Joint Group of Experts on the Scientific Aspects of Marine Environmental Protection (GESAMP) was formed in 2005, i.e., GESAMP-Ballast Water Working Group (BWWG), reporting to the Marine Environmental Protection Committee (MEPC) of IMO to provide independent advice on whether proposed Ballast Water Management Systems (BWMS) using active substances would pose an unacceptable risk to the ships' crews and the general public or the environment. To do this the GESAMP-BWWG first had to consider in detail the "Procedure for approval of ballast water management systems that make use of active substances (G9)" (the Procedure) with which to evaluate the technology. This was in place for MEPC 53 in July 2005. At the same session,

GESAMP-BWWG was also requested to develop a "Methodology for information gathering and conduct of work of the GESAMP-BWWG" (the Methodology). This first version of this Methodology was eventually endorsed by MEPC 58 in October 2008. As technology and science advanced, so did the "Procedures" which were last updated in April 2008 at MEPC 57. Tests to be conducted in freshwater were added, and the "Methodology" was further and lastly updated in June 2022 at MEPC 78. These instruments are seen as "living documents" so that an additional review may be initiated to reflect the experience accumulated from BWMS approval applications evaluation over the years resulting in further revisions and amendments. Of note, GESAMP does not evaluate or comment on the biological efficacy of the BWMS under consideration. GESAMP had recommended that IMO approve >60 BWMS for Basic Approval, and >50 for Final Approval. Once a BWMS is accorded Final Approval, it falls to an Administration to issue a Type Approval certificate based on IMO Guidance found in Guidelines G8 initially, then the Ballast Water Management System Code. These Guidelines as well as the new Code also apply to technology that does not use active substances. In total, >100 BWMS have received Type Approval.

Individual scientists participated in and made meaningful contributions during the discussions at IMO on the ballast water file imbedded as participants either in the various Administration delegations or in specific science-based organizations such as the International Council for Exploration of the Sea (ICES), the World Conservation Union (IUCN), or the Institute of Marine Engineering, Science and Technology (IMarEST) and the World Wildlife Fund (WWF). Amongst others, the specific science-based Guidelines include the way to test BWMS under the mandatory BWMS Code in 2018. There is also Guidance on methodologies that may be used for enumerating viable

organisms for type approval purposes. The Port State Control requirements under BWM Convention envisage the possibility of either indicative or detailed sampling. Scientists provided Guidance on how to do both. Within the Experience Building Phase of the BWM Convention, scientists have been active in testing the efficacy of both testing tools, as well as the various BWMS in real-world situations and across size classes of organisms. Scientific advice is also required under the Guidelines for Risk Assessment (G7).

As with the first edition of this volume, the authors are amongst the leading scientists that have been involved in the ballast water issue worldwide. I commend them on their efforts to further advance the science that underpins BWM Convention.

Chris Wiley
Sarnia, ON, Canada
April 2023

Foreword

As one of the pioneers in European research on aquatic invasions I am delighted to be asked to contribute a foreword to this book. During the 40 years since I published a preliminary summary of known non-indigenous species (NIS) in the Baltic Sea I noted that this subject got more and more attention, which was substantially triggered by the negative impacts of some NIS, such as the European zebra mussel in the Great Lakes and an American comb jelly in the Black Sea. Many terms were in the past used for NIS: e.g., non-native, alien, exotic, and introduced. The human-mediated addition of NIS to the indigenous biodiversity was named as xenodiversity (Gr. xenos – strange; xenofauna, xenoflora, etc.).

In the beginning researchers gathered information on NIS occurrence and their invasion history. It was interesting to note that some NIS, which were introduced a long time ago, were considered native species as they occurred “always” in the Baltic, i.e., as long as systematic biological studies date back. The oldest example is probably the soft-shell clam *Mya arenaria* Linnaeus, 1758, which appeared already by the thirteenth century in Danish waters as reported by studies analysing shells of this bivalve species. This species became so common and widespread in the Baltic Sea that even today’s geological stage of the Baltic Sea is named the *Mya* stage. It was later discussed that *Mya* might have occurred even much earlier here during interglacial periods and that the records from the thirteenth century may be a reintroduction, possibly with Vikings from North America. The unclear situation whether or not a species is introduced or native led to the establishment of a new term naming these species as cryptogenic species. Another case is the barnacle *Amphibalanus improvisus*, which is named Baltic Sea or

brackish water barnacle. It has an almost cosmopolitan distribution and is found in temperate and tropical regions of the Atlantic, Pacific, Indian, and Arctic Oceans as well as in the Baltic, North, Mediterranean, and Black Seas and, interestingly, also in the land-locked Caspian Sea. Its natural range is unknown, but it may have originated in North America. Because of this unclarity this species is also seen as a cryptogenic species. Today, 225 NIS and cryptogenic species have been recorded from the Baltic Sea and adjacent waters. Almost 100 of these species are considered to occur in self-sustaining populations. Worldwide even nearly 2700 marine or estuarine species have an invasion history. New species recordings occur at an ever-increasing rate with now up to ten annual new arrivals in the Baltic Sea in recent years.

Noting the unwanted drastic impacts of some of these species, control and management options were needed. As cost efficiency is in focus, it makes good sense to address the species introduction vector first, which is (assumed to be) dominating. Although vector allocation is not always easy as some NIS may arrive with multiple vectors, it became clear that species are mainly moved with ships and in aquaculture efforts. In shipping, ballast water and biofouling are the dominant means of introduction. Consequently, instruments were developed to address these vectors and this was started with aquaculture guides, guidelines on vessel biofouling, and the IMO Ballast Water Management Convention (BWMC). As nowadays this Convention is in force since September 2017, thereby regulating the amount of viable organisms permitted in discharged ballast water, we may see in future NIS studies whether or not the species introduction rate is changing. This will eventually determine whether or not the standards in this Convention are sufficient to reduce the long-awaited reduction of newly found NIS.

This book completes the knowledge in ballast water management starting with an update since the first edition was published in 2015. In the meantime, BWMC entered into force and this book documents, amongst other things, the experience of certain countries when implementing the Convention from a legal perspective. This is a rare contribution in ballast water management and may help countries to also ratify and successfully implement the convention. My particular interest refers to the risk assessment developments as I was working on this subject jointly with the editors of this book and started to address this subject with them already 20 years ago. This subject is of utmost importance as there is a risk that it may deliberately be used to water down BWMC requirements by widely exempting vessels what should be avoided by all means. It should be noted that exemptions are only meaningful in rare situations, that they are route specific, and that they are not given permanently, but need to be renewed provided the risk situation has not changed.

Having read the first edition with great interest, I am pleased to see so intensive progress and additional subjects being dealt with in this second edition. These two books will be of outstanding value to the experts in this area and also to a broader audience being interested in the ballast water issue and its management. My hope is that this book will provide guidance that more countries ratify and successfully implement BWMC so that one of the most (if not *the* most) important species introduction vector is addressed to protect our aquatic environments from new species introductions and their negative environmental and economic impacts.

Erkki Leppäkoski
Naantali, Finland
April 2023

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M. David, S. Gollasch (eds.), *Global Maritime Transport and Ballast Water Management*, Invading Nature - Springer Series in Invasion Ecology 16
https://doi.org/10.1007/978-3-031-48193-2_1

Introduction: Update of the Global Maritime Transport and Ballast Water Management Book First Edition

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Abstract
Not to repeatedly write another general ballast water management (BWM) introduction chapter, we here instead update the reader on selected ballast water issues with a focus on new developments since the first edition of this book was published in 2015. Possibly the most important key achievement in BWM in these times was the entry into force of the International Convention for the Control and Management of Ships' Ballast Water and Sediments, 2004 (BWM Convention) in September 2017. Undoubtedly, this will globally be a major step to manage ballast water as species transfer vector. Further, we described the amendments to guidelines, which support the BWM Convention implementation and which were agreed since

the first edition of this book was released. To illustrate the BWM Convention implementation complexity, we present, as an example, the phase-in schedule of the Ballast Water Exchange Standard (Regulation D-1) and Ballast Water Performance Standard (Regulation D-2). This phase-in ends in 2024, and from this time onwards, all ballast water discharges from ships, for which BWM Convention applies, need to meet the D-2 standard. We further report that the number of approved BWM systems (BWMS) has more than doubled since the first edition of this book was released, and also new technologies are considered for the purpose of ballast water management. We further report that vessel inspections for compliance with BWM requirements have begun and that penalties are in place for non-compliance with BWM standards. Further, we describe that, according to IMO guidance, biological BWMS commissioning testing is now required after each BWMS installation on each vessel. In addition, the intention of this book and a brief overview of its content are also included below.

Keywords Vessels – Ballast water – Ballast water management – Harmful Aquatic Organisms and Pathogens – International Maritime Organization – Ballast Water Management Convention – Guidelines – Implementation – Compliance monitoring – Update

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1 BWM Update

As BWM is a highly active field of work, substantial changes and progress have occurred since the first edition of this book was released in 2015. Therefore, we did not prepare here another general introduction to the BWM subject, but we present an update to address new key achievements in this field. For an introduction to BWM in general, we recommend to consider the introductory book chapter of the first edition. An overview of recent research

on marine biological invasions is given in Chan and Briski (2017) and Gollasch and David (2019). However, although we had already reported in the previous edition of this book that the number of newly found species was at a record high, this has increased even further so that today's times seem to face the highest rate of species transfers ever with all connected pressures and impacts (Zenetos et al. 2022; Katsanevakis et al. 2013; AquaNIS 2015; Kim et al. 2016; Ojaveer et al. 2016; Olenin et al. 2017; Rabitsch and Nehring 2017; Ulman et al. 2017; ICES 2018). Several new studies underlined the importance of the shipping vector, with ballast water and biofouling being key species introduction pathways[1] (Collin et al. 2015; Tsiamis et al. 2018; Gollasch and David 2019; Gollasch et al. 2019). More recent studies revealed that ballast water was the most important species introduction pathway (Pergl et al. 2020; Liu et al. 2020; González-Ortegón and Moreno-Andrés 2021; Stranga and Katsanevakis 2021; Oliveira Soares et al. 2022; Ricciardi and MacIsaac 2022). It should be noted that the BWM Convention in this context uses the term Harmful Aquatic Organisms and Pathogens (HAOP) so that there is not a limited view to non-indigenous or even invasive species, but it "means aquatic organisms or pathogens which, if introduced into the sea including estuaries, or into fresh water courses, may create hazards to the environment, human health, property or resources, impair biological diversity or interfere with other legitimate uses of such areas" (IMO 2004). As a result, HAOP includes all potentially harmful non-indigenous, cryptogenic and impacting native aquatic species so that referring to non-indigenous and/or invasive species is only a subset of HAOP.

The overarching news since the previous edition of this book was released is that BWM Convention is now eventually in force! The entry into force conditions of BWM

Convention had been met on 8 September 2016 with the accession of Finland, as the gross tonnage of the world's merchant shipping fleet criterium of 35% for its entry into force was met (IMO 2016a). This means the BWM Convention entered into force on 8 September 2017, ca. 13 years after the instrument was adopted in 2004—or more than 40 years after this subject was first discussed at IMO in 1973 (IMO 1973). As of March 2024 the number of BWM Convention Contracting Governments was 97, representing 92.99% of the world's merchant fleet tonnage (for an update visit "Status of Conventions" at www.imo.org, (IMO 2024)).

As stated above, the BWM Convention was adopted more than a decade ago, and the BWM Convention preparational phase also lasted for many years. This means that, even when the BWM Convention recently entered into force, this instrument may require a review to check for amendment needs. Already in 2007, a paper was published suggesting possible BWM Convention review items (Gollasch et al. 2007), but no amendment could have been made before BWM Convention entered into force (IMO 2016b). It was now agreed at IMO that a comprehensive review will be conducted after the practical part of the agreed experience building phase (see below), and the connected data collection was recently completed (IMO 2022a), rather than carrying out several consecutive amendments one after the other.

The BWM Convention is supported by several guidelines as well as guidance documents, and some of these were reviewed and amended since the first edition of this book came out and as we document here:

- Guidelines G8, which describe the testing regime of BWMS, were reviewed, including intersessional work, and an updated version was adopted in 2016. In continuing discussions, the BWM Convention Contracting

Governments expressed the view that the Guidelines G8 should not have a voluntary or recommending nature but became a mandatory instrument. Therefore, the language in this guideline was edited accordingly and it was renamed as a code, i.e., Code for Approval of Ballast Water Management Systems (BWMS Code) (IMO 2018a).

- Another guideline, i.e., the "Guidelines for Ballast Water Exchange (G6)" (IMO 2005a), was amended in 2017 (IMO 2017h) by incorporating a ballast water reporting form similar to the one set out in appendix 1 of the "Guidelines for the Control and Management of Ships' Ballast Water to Minimize the Transfer of Harmful Aquatic Organisms and Pathogens" (Resolution A.868(20)) (IMO 1997).
- Further, the "Guidelines for Risk Assessment Under Regulation A-4 of the BWM Convention (G7)" (IMO 2017a) were amended to address the Same Risk Area (SRA) concept. This concept was developed to exempt vessels from ballast water management requirements in certain areas (IMO 2016d, 2018b). In summary, the area which all selected species may be able to reach with their natural spread is seen as SRA, in which no BWM requirement applies. As an example, an SRA may include several ports in close proximity in two or more neighbouring countries along a coastline, across a strait, a bay or a river mouth. Vessels not calling ports outside SRA may be completely exempted from BWM requirements. Guidelines G7 now include an SRA definition that this is an agreed geographical area to be identified based on a completion of a risk assessment carried out in line with these guidelines. Such a risk assessment is to be based upon hydrodynamic, environmental and meteorological conditions. Further, the extent of connected locations of selected species populations may determine the SRA dimension. It was also added that a risk assessment for an SRA will

typically take the form of a species-specific assessment. Such an assessment could be deemed low risk if the selected species are already present in all selected ports or locations or have a high probability, based on validated models, of establishing throughout the SRA by natural dispersal within an agreed time window. The selection criteria for species in BWM-related risk assessments are addressed in Guidelines G7. However, Guidelines G7 lack details and specifics on how these criteria may be defined. To overcome this, Gollasch et al. (2020) presented target species selection criteria developed during the COMPLETE project (see below). Denmark is one of the driving forces of the SRA approach in Europe, with a focus on the Baltic Sea (IMO 2016d), and in 2020 the Öresund between Denmark and Sweden was designated as SRA (IMO 2022b), which, to our knowledge, is the first SRA designation worldwide. However, in contrast, IUCN stated that SRA cannot be an option for the North Sea due to the inhomogeneous hydrological conditions (IMO 2017b), and we see that the Baltic Sea is even more inhomogeneous in its hydrological conditions, considering, e.g., salinity and water temperatures, so that the Baltic Sea SRA is seen critical, especially when larger areas are considered (David et al. 2013).

- The “Guidelines for Ballast Water Management and Development of Ballast Water Management Plans (G4)” (IMO 2005b) were also amended in 2018 (IMO 2018i) to address possible contingency measures in case BWMS could not be used as intended (see below).
- It was further noted at IMO that additional guidance is needed for tests of scaled BWMS and guidance documents were prepared accordingly (IMO 2017c, d, 2018c, d). These guidance documents were amended further to now also address that the assumptions made for the scaling should be verified for each scaled unit

(i.e., for discrete flow rate models, e.g., 250 m^3/h, 500 m^3/h, 1000 m^3/h). This will be done by mathematical modelling and/or calculations demonstrating that any parameters that would affect BWMS performance are equivalent between base and scaled units. This also means conducting additional performance and environmental tests as specified in the BWMS Code. The testing period for scaled BWMS may be shortened to 3 months.

- To evaluate the environmental acceptability of BWMS using so-called active substances to treat the ballast water, a GESAMP-Ballast Water Working Group (BWWG) was formed early on as an independent body. This group developed the “Methodology for Information Gathering and Conduct of Work of the GESAMP-BWWG”, of which the last version was released as “Revision 5” in 2022 (IMO 2022c). BWMS evaluation is done by considering the effect of the active substance itself and also any disinfection by-products, which are possibly generated during BWMS use. The methodology contains several formulas to address this, including risk characterization of the ship, human health and the aquatic environment. This new version of the methodology requires, amongst other things, more comprehensive toxicity tests to be conducted in freshwater, brackish and marine water, as well as a clear statement of the duration of minimum retention time between ballast water treatment and discharge for a safe discharge of the treated water. Further, an online tool was developed to support the development of data to be submitted for the evaluation of GESAMP-BWWG (IMO 2019a) (see also chapter “Testing Ballast Water Management Systems: Challenge Water Conditions During More Than 100 Test Voyages”).

Keeping track of the various changes in the guidance documents and guidelines underlines that the BWM

Convention implementation is a complex task with challenges occurring in various subject areas including political, administrative, legal, technical and maritime fields. Further, the implementation work has to address both port State and flag State aspects as required by the BWM Convention, which adds another layer of complexity (Gollasch and David 2018; Rak et al. 2019). Noting this complexity, a manual entitled “Ballast Water Management —How to do it” (IMO 2017e) was developed to provide advice on the BWM Convention ratification, implementation and enforcement processes. The manual gives support for Governments, Administrations, shipowners, port State control authorities, environmental agencies and other stakeholders with the aim of encouraging further BWM Convention ratification, implementation and enforcement. David and Gollasch (2018) describe how a European ballast water management approach may be designed. One key feature they suggest is the need for a regional (or wider) cooperation to avoid different requirements in different European seas, as regionally varying approaches would result in confusion and may complicate shipping (David and Gollasch 2018; Rak et al. 2019).

To illustrate the BWM Convention implementation complexity, we present here only one example and this is the phase-in schedule of the Ballast Water Performance Standard (Regulation D-2). In the original version of the BWM Convention, this phase-in ended in 2016 (IMO 2004; David and Gollasch 2008, 2018). However, IMO undertook reviews of the availability of BWMS and concluded that the 2016 end of the D-2 standard phase-in could not be kept. This was partly due to the lack of (shipowner) confidence that BWMS will reliably meet the D-2 standard in worldwide operation and also due to the demanding, i.e., underestimated, onboard installation of such systems (IMO 2014). Also, this phase-in end date could not have been met as the BWM Convention was simply not yet in force. Table

1 shows the now agreed D-2 standard phase-in starting with the BWM Convention entry into force year until 8 September 2024 when all ships to which the BWM Convention applies need to meet the D-2 standard. In short, all new ships need to meet the D-2 standard and existing ships, until they are required to meet the D-2 standard, have to exchange their ballast water according to the Ballast Water Exchange Standard (Regulation D-1). This means that “some” BWM is now required for all ships in international voyages which are registered by Parties to the BWM Convention or all ships, no matter where registered, when calling for ports of BWM Convention Parties.

Table 1 Implementation of the D-1 and D-2 standards (modified after IMO (2019b))[a]

2017	2019	2024
All ships must have • BWM plan • BWM record book • International BWM Certificate Existing ships, built prior 8 September 2017, have to meet D-1 until their D-2 compliance date New ships, built on or after 8 September 2017, have to meet D-2	Existing ships with renewal survey[b] between 8 September 2017 and 8 September 2019: • Case 1: Ships with previous renewal survey between 8 September 2014 and 8 September 2017 have to comply with D-2 by their renewal survey • Case 2: Ships with previous renewal survey before 8 September 2014 have to comply with D-2 at their next renewal survey Existing ships with renewal survey after 8 September 2019 have to comply with D-2 at their renewal survey	From 8 September 2024, all ships have to meet the D-2 standard

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[b]Renewal survey means the IOPPC renewal survey under MARPOL, Annex I

We reported in the first edition of this book that more than 30 BWMS had been certified (type approved) so that most vessels can today be equipped with such systems. We further stated that this is a very fast developing market and that at least 20 more systems were in the certification process. This was not an overestimation as a recent summary revealed that 112 BWMS are now type approved according to IMO requirements and this list was last updated in December 2021 (IMO 2021) for BWMS using active substances and in 2022 for all BWMS (Reviera 2022). Since these reviews were conducted, a few more BWMS received Type Approval, as reported to the recent MEPCs. In addition, the United States Coast Guard certifies BWMS according to their requirements, and as per March 2024, approximately 53 BWMS have received such an approval, others are marked as pending in the process or have pending amendments to previous approvals (USCG 2024). It is hard to predict how the BWMS market will develop, but we have seen that some BWMS manufacturers discontinued their efforts, likely as they were unable to achieve the required system performance in all waters, they were financially uncompetitive or because their business plans became obsolete due to the delayed entry into force of the BWM Convention. However, new BWMS develop constantly with a few new ones to become certified annually. These developing BWMS make in part use of earlier developed BWMS components, but they also include considerations of new technologies, i.e., a new ultrasonic

resonator (Osman et al. 2016), a conical-hole-generated hydrodynamic cavitation as pre-treatment method (Feng et al. 2016), water jet cavitation combined with the generation of hydroxyl radicals (Bai et al. 2018), applying a new concept in the use of engine waste heat (Balaji et al. 2018), considering an ultrasound antifouling technology (Estévez-Calvar et al. 2018), testing a new role of hydrocyclones (Pecarevic et al. 2018), evaluating the effectiveness of heat and UV in combination (Wang et al. 2018), using UV with an in-line vacuum drop (Ottoey Olsen et al. 2020), membrane filtration in combination with venture tubes, UV catalytic TiO_2 and an ozone generator (Shi et al. 2020) and a dual-wave UV-photocatalysis system (UVA/UVC-TiO_2) (Lu et al. 2020a). Further, new active substances were considered for their use in BWMS, i.e., generating oxygen active substances, including ozone, in a plasma reactor (Zhang et al. 2013; Bai et al. 2016), green biocides (Batista et al. 2017), synthetic lipids (Batista et al. 2018), electro-peroxone system consisting of electrolysis and ozonation (Zhang et al. 2018), the possible use of thymol as well as carvacrol as alternative active substances (Kim et al. 2018), adding potassium peroxymonosulfate for the efficient inactivation of bacteria (Xu et al. 2020), continuous bubble reactor using carbon dioxide and its mixtures (Baek et al. 2019), removal of bacteria from ballast water via high-gradient magnetic separation (Lu et al. 2020b), refitting ballast tanks of small vessels as drinking water tanks and filling these tanks with onboard-generated distilled and/or reverse osmosis water (Lu et al. 2021), inert flue gas[2] deoxidation (Bao et al. 2021), ozonation combined with peroxymonosulfate (Rivas-Zaballos et al. 2022), UV in combination with hydrogen peroxide or peroxymonosulfate salt (Romero-Martínez et al. 2021), UV/peroxydisulfate advanced disinfection (Zhang et al. 2023) and UV-LEDs combined with persulfate salts

(Rivas-Zaballos et al. 2023). Despite this large number of newly considered BWMS approaches, shipowners seem to primarily rely on two treatment technologies, i.e., filtration followed by electrochlorination or filtration and UV (Gerhard et al. 2019).

The selection of an appropriate BWMS for a certain vessel is an underestimated challenge, as many aspects need to be considered. Firstly, the system limitations need to be consulted and compared with (a) the intended or planned vessel routing, and (b) with the water conditions to be treated by BWMS, which especially refers to salinity. Secondly, it needs to be evaluated if requirements to run BWMS, such as power consumption and storage capacity of active substances, are compatible with the vessel. Thirdly, the engine room (or wherever BWMS is to be placed) needs to be checked to ensure the dimension fits. Certainly, the purchase and running costs are additional selectors (Yonsel and Vural 2017; Šateikienė et al. 2018; Vorkapić et al. 2018; Chen et al. 2023). In this respect, retrofitting seems to be even more challenging as installations on new builds (Jee and Lee 2017).

Almost all of the above-stated BWMS were developed to be installed on board of a ship. In contrast, at least seven BWMS were tested for their use on land or on a barge. This concept requires that untreated ballast water is pumped from a ship upon arrival in a port to either a land-based or barge-located reception facility, where this will either be treated and released into the environment, or it is treated and stored to be pumped on board of ships that require a ballast water uptake. The suitability of these methods is currently being tested, with some positive first indications of their use in commercial ports (IMO 2017g; Gunton 2017; NWP 2019; Zhang et al. 2021). However, Wang and Corbett (2021) concluded that the vessel-based BWMS is more cost-effective under current ballast water discharge standards, and that the barge-based BWMS will be more

cost-effective when more stringent ballast water discharge standards will be implemented in the future. This evaluation considers, amongst other things, BWMS footprint and costs for retrofitting. They further suggest that for the barge-based BWMS, the ports may charge BWM fees or may increase port dues according to the volume of ballast water to be treated.

Due to limited information available, it remains unclear how many BWMS were so far installed on existing vessels. A former investigation revealed that 2410 ships were equipped with BWMS already in 2015 (IMO 2015), and a recent summary, as a result of the Experience Building Phase, documented that >13,580 ships have BWMS installed (IMO 2022a). The study documented that few BWMS were operated routinely and even fewer are monitored or evaluated for their performance after commissioning. The majority of the performance monitoring events considered technical/mechanical performance, such as filter pressure difference, power consumption, filter backflush frequency, and much fewer assessments were made to check if the D-2 standard was met. On the downside, several technical BWMS malfunctions were reported. In most cases, this refers to failing sensors/controls, piping/valve systems and problems with filtration, as well as problems during routine ship operations (IMO 2015, 2022a; Jang et al. 2020; Peperzak et al. 2022). Because of these BWMS failures, IMO has agreed to conduct biological performance tests after commissioning of each installed BWMS (IMO 2017d, f). At the 73rd meeting of the Marine Environment Protection Committee (MEPC) (October 2018), it was recommended to establish a correspondence group to consider the commissioning testing of new BWMS installations on existing ships and to ensure that it is addressed for incorporation in the 2019 version of the survey guidelines under the Harmonized System of Survey and Certification

(HSSC) (IMO 2018e). It was eventually agreed that commissioning testing has to be conducted using representative ballast water discharge samples (Gollasch and David 2017), which should be analysed for both size classes included in the D-2 standard using indicative analysis methods (IMO 2018e). This biological commissioning testing of each installed BWMS is required since 1 June 2022.

Starting with MEPC 75, planned to be held in March/April 2020, meetings were postponed due to the Corona pandemic and this and the following MEPCs were held virtually until MEPC 79 was arranged again as an in-person meeting in December 2022. Recent BWM-related work until and including MEPC 80 (July 2023) covered: a protocol for the verification of Compliance Monitoring Devices [adopted], an agreement of the GESAMP-BWWG evaluation to grant and not grant new Basic and Final Approvals of BWMS using active substances [adopted], a revision of the Ballast Water Record Book [adopted], an agreement that it should be permitted to use ballast tanks for temporary storage of treated sewage and grey water [adopted], working towards guidance for ships encountering challenging water quality resulting in improperly treated ballast water [ongoing]. Further, the data gathering phase of the Experience Building Phase was completed and current activities at IMO focus to develop a Convention Review Plan, also considering the supporting guidelines and guidance documents (see below).

To solve the problem of improperly treated ballast water due to BWMS failure, IMO also summarized contingency measures, i.e., measures to take when a ship is unable to manage ballast water in accordance with its approved ballast water management plan to meet the D-1 or D-2 standards, but with a view to ensuring the protection of the marine environment and ship safety and minimizing any impacts on the continuity of port and ship operations.

Contingency measures include repair of BWMS at the ballast loading port, repair of BWMS en route, ballast water exchange (BWE) options instead of using BWMS, including making use of a designated ballast water exchange area, discharge ballast water to another ship or to an appropriate port-based reception facility, internal tank-to-tank ballast water transfer, ballast water retention on board or the use of water from a public water supply as ballast. The addition of contingency measures required a minor amendment to the “Guidelines for Ballast Water Management and Development of Ballast Water Management Plans (G4)”, which would not require a complete revision of these guidelines (IMO 2018f, g, h).

The BWM Convention includes provisions that the ballast water of a ship may be checked whether or not it is in compliance with the ballast water performance standard. Consequently, several countries check the ballast water conditions and evaluate if ships followed BWM requirements. The BWM Convention also says that sanctions provided for by the laws of a Party in this respect shall be adequate in severity to discourage violations. As an example, the ballast water of selected vessels calling for the Port of Hamburg, Germany, was checked regarding BWM requirements. In January 2018 a case was reported that officials of the Water Police found a violation of BWM Convention requirements. This violation was that the ship had not exchanged the ballast water, although this was required by the BWM Convention, and it would have been possible for the ship to carry this out on the intended vessel route. Consequently, the authorities ordered a security deposit for the approximately 15,000 tonnes of ballast water, which had already been discharged at the berth in an illegal manner (Vessel Tracker 2018). Nowadays, a new online service is available to get a ballast water discharge permit for the Port of Hamburg. In accordance with Articles 8, 10, 13 and 18 of the “Gesetz zur Ordnung des

Wasserhaushalts" (Federal Water Act) in conjunction with the "Hamburgisches Wassergesetz (HWaG)" (Hamburg Water Act) and the "Hafenverkehrsordnung" (Port Traffic Regulations) Article 41 a–c, a permit is required before you may start discharging ballast water. In this online tool, a ballast water discharge permit may be applied for and your request is automatically sent to the competent authority. There are specific questions to apply for this permit, including to indicate who you are, vessel specifics, planned vessel berth in Hamburg, water origin (North Sea, Baltic Sea or outside), was ballast water management conducted to meet the D-l or D-2 standards and the amount of water intended to be discharged.[3]

In the first edition of this book, we also documented the past and ongoing BWM research activities, especially regarding risk assessment and decision support systems, which were supported by the work conducted during various research projects, including the EU-funded VECTORS[4] project and the IPA Adriatic strategic project BALMAS.[5] A new ballast water management risk assessment model was developed to support the implementation of most efficient management measures, which also includes a flowchart decision support system model (David and Gollasch 2019).

BWM research efforts continued, and just to name one, a project was recently completed, which addressed ballast water and biofouling together. This was the Interreg-funded project COMPLETE[6] and COMPLETE Plus,[7] which had a Baltic Sea focus (Outinen et al. 2021). The prime focus of both projects was the harmonized implementation of the BWM Convention.

In conclusion, although major steps ahead were achieved in diverse BWM fields, the complexity of this subject leaves room for different interpretations and results

in unanswered questions so that more research activities are needed.

IMO noted the lack of knowledge and to overcome this, a so-called Experience Building Phase was initiated with three stages, i.e., data gathering, data analysis and a review of BWM Convention and its supporting guidelines and guidance documents. The first phase was completed with IMO Member States funding research to address research needs and documentation, such as a summary of certified ships, an overview of the operational status of BWMS, documentation of circumstances of any failures to achieve BWM standards, evaluate BWM requirements compliance rate and collect results of studies regarding methods for ballast water sampling and analysing ballast water samples (IMO 2016e, 2018d, 2022a). As a next step, the Data Gathering and Analysis Plan was approved, and a Correspondence Group was established to select, amongst other things, priority items for the Convention Review Plan (IMO 2022a).

This means the work at IMO (and elsewhere) on BWM subject will keep a priority, and it is expected that many new outcomes will be delivered, which likely also result in further amendments to the BWM Convention and its supporting guidelines and guidance documents. At the most recent MEPC meeting considered here (MEPC 80, July 2023), it became clear that the development and validation of new analysis methods of ballast water samples (Compliance Monitorng Devices) becomes more prominent (see also Peperzak et al. 2018; Cullen 2018, 2019; Lundgreen et al. 2018; Outinen and Lehtiniemi 2019; IMO 2019c, d, e, f, k, l, m, n, o, p; Andreasen et al. 2020; Tamburri et al. 2020; Ding et al. 2021; Cai et al. 2022; Casas-Monroy et al. 2022; Hou et al. 2022; Peperzak 2023) and that retrofitting of BWMS on existing ships undoubtedly is a challenging task (e.g., IMO 2019g, h).

A further literature screening resulted in the following BWM aspects, which may need to be addressed in the future:

- Considering the size classes in the D-2 Ballast Water Performance Standard, there are more and more statements to consider addressing organisms below the lower size threshold given in the D-2 standard, i.e., organisms below 10 µm in minimum dimension. In this size range, there are not only bacteria and viruses but also phytoplankton species (including harmful algae) and smaller zooplankton (Wiltshire and Dürselen 2004; Gobler et al. 2011; Gollasch et al. 2012; McKibben et al. 2015; Kim et al. 2016, 2019; Lv et al. 2017; Soleimani et al. 2017; Hwang et al. 2018; Trindade de Castro and Veldhuis 2018; Hess-Erga et al. 2019; Petersen et al. 2019; Reavie and Cangelosi 2020; Wang et al. 2020). In this context, it is interesting to note that the interim California State Lands Commission standard regarding viruses is planned to go into effect in January 2030 and the final standard in 2040. The proposed interim standard requires less than 10,000 viruses per 100 mL and the proposed final discharge standard requires zero detectable viable organisms for all organism size classes, including viruses (Ceballos Osuna et al. 2021). If the latter can be achieved remains to be evaluated (Kim et al. 2019).
- Further to species transfers, the spread of antibiotic resistance with bacteria is a major threat to ecosystems and human health. The occurrence of antibiotic resistance genes in ballast water was documented in considerable levels so that a mitigating measure is recommended to avoid the risk of antibiotic resistance genes and bacteria transfer across oceans (Lv et al. 2020, 2021). Another study found elevated levels of antibiotic resistance genes in ballast and port waters. It was

therefore suggested that ballast water discharges have the potential to cause higher concentrations of certain antibiotic resistance genes in ballast water discharge areas or that ballast tank conditions may result in a selective pressure for some of these genes (Gerhard and Gunsch 2020).

- So far the BWM Convention Regulations were not re-opened for amendments, but this will be coming in the BWM Convention review process, which is foreseen to begin shortly as a holistic review of the Convention and is expected to last until 2026 (MEPC 85) (IMO 2022d).
- A genetical analysis, i.e., metabarcoding, was suggested to evaluate the concentration of indicator microbes in ballast water as a compliance control method to proof ballast water management standards (Gerhard and Gunsch 2019). This technology was further applied to conduct port baseline surveys, which are required when exemptions from ballast water management requirements are considered. The morphological taxonomic analysis makes these surveys extremely cumbersome and expensive. Although the environmental DNA analysis alone cannot substitute traditional taxonomic efforts, metabarcoding enabled the detection of previously recorded and also new species, even when they occurred in low abundances (Ardura et al. 2020; Rey et al. 2020; Duarte et al. 2021).
- Ballast water discharges introduce not only organisms but also chemicals. High levels of heavy metals were found in ballast water to be discharged in different regions (Soleimani et al. 2016; Tjahjono et al. 2016, 2017; Dobaradaran et al. 2018; Tolian et al. 2020). However, the environmental and human health impact of heavy metals is largely ignored, but should be considered when planning BWM scenarios. Further, disinfection by-products are generated by BWMS making use of active substances. These substances reach the environment

even when the ballast water is neutralized prior discharge (David et al. 2018a; Dock et al. 2019, 2020; Maas et al. 2019; Grote et al. 2022) but are assumed as to not cause negative impacts after GESAMP-BWWG evaluation and Final Approval issuance.

- Details of the ballast water discharge profile in a port are one of the basic elements in the decision-making process regarding ballast water risk assessment and management (David et al. 2013). However, ballast water reporting is lacking in many places so that the ballast water discharge needs to be calculated to implement feasible and efficient BWM measures enabling environmental studies, including, e.g., the evaluation of long-term accumulation risks of disinfection by-products from BWMS making use of active substances, as well as for discharges of other chemical compounds (David et al. 2018b).
- Recognition of on board crew training as an important aspect is inadequate. On board training of crews to operate BWMS is essential as misuse may result in (a) BWMS damage, malfunctions, (b) health problems due to wrong handling of active substances, (c) financial penalties in case BWM standards are not met during inspections and (d) certainly environmental damage (Frančić et al. 2015; Ghosh and Rubly 2017; Kuroshi et al. 2019; Ceballos Osuna et al. 2021).
- Studies have shown that the operation of BWMS followed by BWE increases the efficacy to remove or inactivate organisms. This is especially the case when the ballast water uptake is in a very different salinity as the area where BWE will be performed. As an example, organisms pumped on board in a freshwater port will be exposed to a salinity shock when BWE is conducted in fully marine waters (Briski et al. 2013, 2015; David et al. 2013; First and Drake 2017; Paolucci et al. 2017; David and Gollasch 2019). The suitability of this BWM approach needs to be

evaluated on a case-by-case basis and no uniform recommendation can be given due to regional and safety specifics. In certain USA locations (Great Lakes), BWE plus BWMS operation is required by regulations to achieve more reliable and increased biological treatment efficacy (Bradie et al. 2021). In other cases, e.g., the Amazon River, this practice is performed as a contingency measure when BWMS performance may be strongly challenged by local water conditions (IMO 2019i).

- The living organisms found in ballast water and bilge water (!) of pleasure boats should also be considered when planning BWM scenarios (Campbell et al. 2016; Fletcher et al. 2017). In addition, invasive goby larvae were surprisingly found alive in a cooling system of a small watercraft motor so that this potential species transport vector should also be considered (Bussmann et al. 2022).
- Neglected so far was also the possible impact of ballast water transported along the northern, i.e., Arctic, route should this become ice free. The considerable shorter distance between the northern Atlantic and Pacific Oceans, compared to a vessel route through the tropics, may have an impact on species survival en route. This impact may be twofold: (a) shorter voyage may result in higher organisms survival en route, and (b) the voyage in the Arctic region would avoid a tropical passage, thereby not heating up the ballast water en route, which in turn may also amplify the survival of species (Chan et al. 2018). Further, the cooling effect during the Arctic route may also negatively influence the survival of organisms.
- Another overlooked aspect is the biofouling on the inside of a ballast tank. This was observed multiple times and may result in spawning events of adult organisms in ports when organisms are exposed to changes in water conditions due to ballast water uptakes so that a species

may be introduced when this ballast water is released. It would also be of interest to study if such an in-tank biofouling may compromise the performance of a BWMS to meet the D-2 standard (after an in-tank spawning event occurred) (Gollasch and David 2019; Gollasch et al. 2019).

- Although already published in 2017 as the first study of its kind, Matiddi et al. (2017) confirmed the presence of microplastics in ballast water of commercial vessels arriving in the Port of Bari, Italy. They found up to 1410 items per m^3, which is more than thousand times higher in number than occurring in the natural waters of the Mediterranean Sea (0.15 items per m^3). Possible consequences of this phenomenon remain to be seen, but Naik et al. (2019) assumed that microplastics in ballast water are a potential risk to the environment and human health as they might be a carrier for chemicals, antibiotics, metal ions and organism. However, a filtration technology was proposed to mitigate microplastic pollution (Naik et al. 2021), but its feasibility was not tested in full scale. We also frequently find plastic fibres in samples taken at discharge of treated ballast water (Fig. 1).
- A study estimates that the implementation of the BWM Convention will reduce the number of new non-indigenous species findings by 17% (only) (Gren et al. 2022), and Hulme (2021) concluded that the current legislative and scientific tools addressing biological invasions are insufficient to handle this growing threat.

Fig. 1 Sample being analysed under the stereomicroscope containing different plastic fibres

2 Intention of This Book

After the first edition of this book was published, substantial progress was made in BWM field (see above), of which the most impacting was the entry into force of the IMO BWM Convention in September 2018. The implications of this and other new developments are addressed in this book to catch up with the new achievements in this highly dynamic field of work.

The editors of the first edition of this book invited the authors who had contributed to the previous book version as well as new authors to address further scientific disciplines related to BWM field. The experience of all authors uniquely enabled us to address these additional

subjects, which are substantially widening BWM knowledge beyond the limits of the first edition. Therefore, both editions may be considered (also in parallel) to get the full BWM picture.

We expect that this new edition has many answers to questions readers might have had after having “digested” the content of the first edition. We therefore believe that this book is of interest to a wide field of people who (have to) deal with BWM. As in the previous edition, the chapters are written in such a way that they are also of interest to the wider public, however, not neglecting the necessary level of detail.

3 Book Content

After this introductory update, the book continues with lessons learned during performance testing of BWMS; it gives a summary of challenge water conditions in shipboard tests of more than 100 test voyages, addresses concerns that experts may have of BWMS using active substances, reflects the port State authorities perspectives for Compliance Monitoring and Enforcement of the BWM Convention, documents the development and testing of methods for compliance control tests with BWM requirements, explains BWM options in ports, and introduces sediment management, which is a largely overlooked subject. The book continues to explain the importance of databases to store specific information which is essential in BWM field, including early warning systems. The book ends with presenting the legal aspects to consider during BWM Convention implementation, written as a guidance for IMO Member States facing the complex task of implementing this convention. As in the first edition, we conclude with a chapter documenting further knowledge gaps and by highlighting additional research needs.

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Footnotes

1 It may be interesting to note that the subject biofouling becomes more of a focus at IMO as shown by the submission of documents to the last MEPC meetings addressing this species transport vector.

2 Inert flue gas consists of nitrogen (N_2) and carbon dioxide (CO_2).

3 https:serviceportal.hamburg.de/HamburgGateway/Service/Entry/BallastWaE. Last assessed March 2024.

4 Vectors of Change in Oceans and Seas Marine Life, Impact on Economic Sectors (VECTORS), European Community's Seventh Framework Programme (FP7/2007–2013) under Grant Agreement No. [266445].

5 Ballast Water Management System for Adriatic Sea Protection (BALMAS), IPA Adriatic Cross-Border Cooperation Programme strategic project.

6 Completing management system to reduce the risk of invasive species introduction in ship's ballast water and by hulls biofouling for environmental protection of the Baltic Sea (COMPLETE). Interreg Baltic Sea Region Programme.

7 https://interreg-baltic.eu/project/complete-plus/. Last assessed 30.01.2023.

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M. David, S. Gollasch (eds.), *Global Maritime Transport and Ballast Water Management*, Invading Nature - Springer Series in Invasion Ecology 16
https://doi.org/10.1007/978-3-031-48193-2_2

Type Approval Tests of Ballast Water Management Systems, What Have We Learned in >10 Years Testing

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Abstract
This chapter highlights the challenges involved in the type approval testing of Ballast Water Management Systems (BWMS). IMO required such tests with its Guidelines G8. This guideline was prepared with best efforts during substantial debates, but in practice, some requirements turned out not to be relevant, and other important aspects were found to be missing. It was concluded at IMO that the Guidelines G8 requirements do not represent enough challenging test conditions to represent all waters where ballast water is taken up by vessels. Therefore, BWMS which have received type approval under the previous Guidelines G8 may be found non-compliant if BWMS is operated in more challenging water conditions as the system was exposed to during the tests. MEPC67 (October 2014) agreed that Guidelines G8 should be revised. The revision process ended at MEPC70 in October 2016. In further discussions, BWM Convention Contracting Governments expressed the view that the new Guidelines G8 should not have a voluntary or recommending nature but should become a mandatory instrument. Therefore, the language in this guideline was edited accordingly and it was renamed as a code, i.e., Code for Approval of Ballast Water Management Systems (BWMS Code). This book chapter describes the Guidelines G8/BWMS Code editing suggestions of the authors, which were based on their long-lasting experience in testing BWMS, and it continues to describe the agreed BWMS Code amendments. Independently of IMO work, the United States Coast Guard established their own BWMS test guidelines. The differences of these guidelines compared to the BWMS Code are also discussed, and recommendations are suggested to improve the test regime to make BWMS more fit for purpose.

Keywords Vessels – Ballast water management – Convention – Ballast water management systems – Type approval testing – BWMS Code

1 Introduction

It was recognized that the discharge limits of viable organisms set in Regulation D-2 of the BWM Convention (IMO 2004) may only be met by some kind of ballast water treatment (Lawrence and Cordell 2010; Casas-Monroy et al. 2015). Consequently, various water treatment technologies were considered by manufacturers of Ballast Water Management Systems (BWMS). Today, most BWMS consist of a combination of mechanical, physical and/or chemical processes to eliminate or inactivate organisms in ballast water (Tsolaki and Diamadopoulos 2010; Lloyds Register Report 2012; Balaji et al. 2014; David and Gollasch 2015; Stehouwer et al. 2015; Bai et al. 2016; Ren et al. 2016).

BWMS need to be rigorously tested in land-based (kind of laboratory conditions) and shipboard (real BWMS use conditions) settings to document their performance in different water conditions. In the beginning, the test requirements were outlined in the IMO Guidelines G8 (IMO 2008). However, several IMO member states, which are involved in the certification of BWMS and shipping organizations, e.g., the International Chamber of Shipping (ICS), International Association of Classification Societies (IACS), International Association of Independent Tanker Owners (INTERTANKO) and the World Shipping Council (WSC), communicated weaknesses of Guidelines G8 to IMO. Understanding the need to review and amend Guidelines G8 to make them more fit for purpose (Gollasch and David 2015), an intersessional IMO correspondence group was launched to work between MEPC meetings. As a

result, an updated version of the Guidelines G8 was prepared and adopted by MEPC in 2016 (IMO 2016).

In continuing discussions, BWM Convention Contracting Governments expressed the view that the Guidelines G8 should not have a voluntary or recommending nature but should become a mandatory instrument. Therefore, the language in this guideline was edited accordingly and it was renamed as a code, i.e., Code for Approval of Ballast Water Management Systems (BWMS Code) (IMO 2018).

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2 Recommended Amendments to BWMS Test Requirements Based on the Authors' Experience

2.1 Recommendations Based on Land-Based Test Experience

Land-based testing primarily aims to evaluate the biological efficacy of a BWMS in the relatively controlled conditions of a land-based setup. Compared to the original Guideline G8, the revised Guideline G8 introduced vital improvements to the test protocol, which became mandatory in the BWMS Code (IMO 2018). These improvements include an evaluation of the minimum holding time and a regrowth assessment. Moreover, augmentation of the challenge water using Standard Test Organisms (STOs) and organic matter properties were clarified aiming to improve the comparability of test results among various test facilities. However, several issues are still insufficiently addressed.

2.1.1 Oxidant-Demand and Concentration × Time Value (CT-Value)

To understand why oxidant-demand is a relevant factor, let's contrast the issue with the following aspect that is evaluated well during land-based testing: Ultraviolet

Transmission (UVT). UVT of the challenge water has long been recognized as a limiting factor by impacting the UV-Intensity (UVI) of a UV-based BWMS. Water with low UVT absorbs the radiation, which greatly reduces the UVI available for disinfection. A BWMS can monitor the UVI and/or UVT to control the delivery of the minimum radiation dose needed for disinfection. Dosage control is achieved by adjusting either the ballast flow rate or the power output to the UV lamps.

At the onset of land-based testing, manufacturers must declare a minimum UVT performance claim, which is evaluated during land-based testing. The challenge water can be adjusted using aromatic substances to adjust the UVT and test the performance claim. As a result, the minimum UVT or minimum UVI is typically listed on the type approval certificate of the BWMS. As soon as the minimal UV dosage cannot be delivered, the BWMS must raise an alarm to notify the crew of improper treatment. In this manner, a relevant system design limitation is adequately incorporated into the control and monitoring equipment of the BWMS, aiming for consistent water treatment and environmental protection.

However, in the ballast water industry, it has not been widely recognized that oxidant-based BWMS have a similar limiting factor to UVT, namely the oxidant-demand of the water. Oxidant-demand is a measure of oxidant-decay over time and can vary greatly under disparate water qualities and ambient water temperatures. Like a low UVT, oxidant-demand is mainly caused by the presence of aromatic organic substances in the water, being part of the Dissolved Organic Carbon (DOC) fraction (Moreno-Andres and Peperzak 2019). In water with high oxidant-demand, the Total Residual Oxidant (TRO) level will drop to below detection levels within hours after treatment, whereas in water with low oxidant-demand, this decline can take several days.

TRO concentration combined with the rate of decline ultimately determines the disinfection dosage of oxidant-based BWMS. This dosage is defined as the Concentration × Time value (CT-value), expressed as mg/L-minute, which is a well-established concept in the drinking water treatment industry. To determine the correct CT-value, TRO levels must be monitored during ballasting and during storage time. Based on the oxidant-demand, the average TRO concentration over a given time can be calculated, resulting in the corresponding CT-value (DNV 2017).

Currently, most oxidant-based BWMS are solely designed to monitor the inline TRO concentration during ballasting and de-ballasting, but do not monitor in-tank TRO levels.

Instead of declaring the minimum CT-value manufacturers suffice to clarify the maximum TRO concentration during ballasting. This claim is indeed monitored during testing. Until now, BWMS have been successful in passing stringent land-based test regimes purely based on recording the initial TRO concentration even in widely varying water quality conditions, so this approach has not been without success. However, the current requirements placed in UV-based BWMS to monitor the impact of water quality on UV dosage is not equally matched with a similar requirement in oxidant-based BWMS.

There are two ways to amend the BWMS Code to provide a concrete basis for including oxidant-demand as a performance claim during land-based testing. The first and easiest way is to add oxidant-demand to the list of minimum challenge water requirements for land-based tests, next to Total Suspended Solids (TSS), DOC, Particulate Organic Carbon (POC) and so on. In that way, all oxidant-based BWMS must pass a set of challenging land-based cycles that show the D-2 standard is reached without any signs of insufficient disinfection or regrowth. Secondly, oxidant-

based BWMS could be explicitly required to declare a minimum CT-value instead of a TRO concentration, which is the current practice. This CT-value would have to be included on the type approval certificate. Incorporating a CT-value would necessitate manufacturers to include an in-tank TRO monitoring system to be able to monitor TRO concentration over time. Thus, including a CT-value as a requirement would lead to changes in currently approved BWMS. As a logical consequence, the CT-value would also introduce a new concept known as *maximum* allowable hold time restriction. As TRO degrades to below detection levels, the CT-value gradually drops over time until the minimum CT-value is reached, at which point BWMS should raise an alarm warning the crew that the treated ballast water is at risk for in-tank regrowth.

2.1.2 Total Suspended Solids

The BWMS Code and ETV protocol require a set of challenging but not rare conditions that the challenge water must contain during land-based testing. TSS is one of these requirements. The rationale for including TSS is that most BWMS have a filter to remove larger organisms prior to disinfection. Filters are challenged by high TSS loads in the right particle size range depending on filter pore size. In water containing high TSS loads, filters could reduce throughput or clog entirely, sometimes requiring manual cleaning to become operable again. As ballasting is frequently associated with cargo unloading to balance the vessel, any filter malfunction may result in issues with completing cargo discharge operations and consequently having repercussions on vessel and unloading terminal operations. Reliable and predictable filter performance is thus a vital part for any merchant vessel, albeit often overlooked at time of BWMS purchase. The BWMS Code and ETV protocol require challenge water to contain more

than 1 to more than 50 mg/L TSS depending on salinity. These ranges were determined to reflect typical TSS loads in ports around the globe. However, even when many ports never reach TSS loads of 50 mg/L, there are certain locations that reliably and consistently exceed these levels by order of magnitude. For example, the ports of Hamburg, Shanghai and New Orleans can contain well over 500 mg/L or even reach 1000 mg/L TSS (Jang et al. 2020). Many ballast water filters were never tested under these conditions and invariably clog when installed on a vessel that regularly visits ports in these regions. Certain manufacturers reacted proactively by conducting various kinds of filter stress tests. One test facility specifically designed a stress test to resemble Shanghai harbor conditions (Peperzak et al. 2022). However, it would be better if manufacturers were required to deposit a maximum TSS performance claim to be tested during type approval. The impact of increasing TSS levels on the BWMS flow rate could be presented graphically and provide much needed transparency to the market when selecting between different BWMS types. The BWMS Code should therefore be amended to require a filter stress test to be part of the land-based type approval. Note that the particle size distribution of TSS is of vital importance, as certain standardized test dust particles like Arizona dust are so fine that they pass most filters unhindered. The BWMS Code therefore should also specify the particle size distribution of TSS used for augmentation to represent naturally occurring sediment present in these challenging ports.

2.2 Recommendations Based on Shipboard Test Experience

In general, the shipboard tests of BWMS should focus on the practicability of BWMS, its seaworthiness and its

biological efficacy. The objectives of the shipboard testing include verifying that the installed equipment continues to maintain effectiveness during shipboard operation.

The experience of SG and MD in shipboard testing becomes clear when considering that they participated in such tests since 2005 and have conducted more than 120 test voyages (see chapter “Testing Ballast Water Management Systems: Challenge Water Conditions During More Than 100 Test Voyages”). This knowledge resulted in the below-stated recommendations on how the Guidelines G8 may be amended (Gollasch and David 2015).

Several test requirements, which make sense in the land-based test setup, cannot be used on board of ships. The test team needs to fly all sampling gear and laboratory gear as well as consumables to the port(s) where the ballast water operations will be conducted. Therefore, a “mobile laboratory” is needed, which restricts the use of very fragile, bulky and heavy instruments. One lesson learned is that a certain level of compromise is needed for the shipboard tests in terms of what should be done and what can be done. This also is reflected in the number of test team members required to do the analysis within the time limit. This is not only a cost factor, but also, assuming the test team needs to sail with the vessel between uptake and discharge (a voyage is required by the BWMS Code), the cabin and lifeboat availability of the vessel may cause limitations, especially when crew changes occur. Should this not be available for the test team, travel between the ballast water uptake and discharge ports becomes necessary, which may become challenging when both ports are not within driving distance.

Understanding of ship operation, nautical and maritime sectors is also essential for a smooth planning and especially for troubleshooting events when, e.g., the tanks to be used have to be selected, the water flow at the sampling point needs to be arranged, etc.

We also learned that many things can go wrong and that a great level of flexibility is needed with a Plan B constantly being ready, which means among other things, that sufficient consumables need to be available for test repetitions.

To reach the maximum possible quality of results, ETV requires positive control samples to be processed for the bacteria. This is impossible when the departure port of the vessel, to where the sampling team needs to travel, is located outside the sampling team home country, because the transport of such material needs to be declared and in many cases, it is simply forbidden to import living bacteria.

2.2.1 Test Duration

BWMS Code requires that shipboard tests have to span in duration over a test period of not less than six months. This requirement was included to evaluate BWMS long-term durability and any possible aging effects of BWMS components (e.g., filters, UV-lamps). However, the previous Guidelines G8 lacked a requirement that BWMS had to be operated constantly for all ballast water operations during the six-month testing period. Therefore, BWMS may have been used only during the three shipboard tests, but not routinely. As this was in contrast to the original intention of Guidelines G8, it was changed to clearly state that BWMS should be operated routinely during the entire six-month test period (see BWMS Code, Annex, paragraph 2.8.11.2).

2.2.2 Number of Tests

The BWMS Code requires three shipboard tests to be conducted over a period of six months. It should be noted that one of the main critical points stressed by the shipping industry in BWMS type approval process was that BWMS test requirements were not robust enough to provide confidence to ships to operate in accordance with the BWM Convention requirements. Furthermore, this point is

certainly not only of the shipping industry interest, but it is about achieving the prime goals of the BWM Convention, which is to protect the natural environment, human health and resources from the negative effects of the transferred harmful aquatic organisms and pathogens, as well as to continue providing safe and efficient shipping globally.

Most vessels sail to many different ports all around the world and all around the year, which results in loading ballast water of vastly different conditions. These range from fresh water (<0.5 PSU) to fully marine water (>30 PSU, even >40 PSU), from temperatures around 0 to more than 35 °C, a quite different organism compositions and concentrations, and very different sediment loads—from very clear water in some marine ports to frequently very high sediment loads in ports situated in rivers or estuaries.

All the above very clearly indicates that with only three tests, it is practically impossible to get even close to all the different conditions that would be needed to really show that BWMS can perform well to meet the D-2 standard requirements when exposed to different conditions. BWMS type approval certificates should therefore clearly state BWMS limitations to avoid vessels being in non-compliance in some “specific” conditions.

Therefore, it would be particularly important to conduct more shipboard tests in different conditions. We recommended that at least five consecutive successful tests must be conducted over the six-month testing period, and that these tests should be conducted in different water conditions, climate zones and salinity regimes to better reflect the diversity of real-world ballast water uptake conditions. This is also very much in line with the latest USA BWMS test requirements (ETV Protocol 2010). However, IMO was unable to agree on such an amendment of the BWMS Code. What was agreed is that BWMS will only be certified for the conditions under which they were tested (see BWMS Code, Annex, paragraph 2.31). This

means when limiting the test conditions, BWMC certificate will reflect this.

2.2.3 Flow Rates

All type approval testing should realistically represent the flow rates BWMS is designed for, and the flow rates should be monitored during the tests. A deviation from this flow rate may result in an unrepresentative over- or underkill of organisms, as the treatment may be higher or lower than calculated. We noted that the flow rate varies with filling and discharging of ballast tanks, hence BWMS should be able to manage these in positive and negative way, i.e., about 20% lower and 20% higher flow rates than the pump capacity/BWMS Treatment Rated Capacity (TRC).

We recommended that the BWMS Code should include a definition of the range/limits of the flow rates during testing, i.e., the average flow rate during the test should not be more different than 10% of BWMS TRC. A flow rate documentation was previously not required for shipboard tests, and this was added. However, the percentage TRC deviation could not be agreed. Instead, the BWMS Code states that during testing BWMS shall be operated at TRC for which it is intended to be approved and that this should be documented (see BWMS Code, Annex, paragraphs 2.8.4 and 2.17).

2.2.4 BWMS Service and Major Component Changes

After the six-month test period began, BWMS should only be serviced as per the operations and maintenance plans until the end of the testing period, and we recommended to establish a proper documentation of these events. Further, major components of a BWMS, which may affect the efficiency of a BWMS, should not be changed during test runs. Furthermore, major component changes may result in

the requirement to repeat test runs. This is now clearly stated in BWMS Code (see BWMS Code, Annex, paragraph 1.10).

2.2.5 Normal Ship Operations

BWMS tests are to be conducted during normal ballast water operations of the ship (e.g., see BWMS Code, Annex, paragraph 2.8.4). As ships usually do ballast water operations in ports, the uptake and discharge tests should be conducted in ports and not during navigation. In addition, vessels usually take up ballast water in one port and discharge it in another so that a vessel voyage becomes necessary between the uptake and discharge tests of a BWMS to fulfill the normal ship operation requirements. However, it was not explicitly stated earlier where the ballast water operations should be conducted during the test runs and that a vessel voyage should occur between ballast water uptake and discharge. This has now been added to BWMS Code (see BWMS Code, Annex, paragraph 2.6.3).

2.2.6 BWMS Operation During Tests

BWMS developer has to ensure that for the shipboard test, the ship’s crew is familiar with BWMS and equipment and that the crew is sufficiently trained to operate BWMS and equipment. We recommended (Gollasch and David 2015) that a representative of BWMS developer may attend the test voyage(s) to ensure that questions by the vessel crew regarding BWMS and its equipment can be answered promptly that not the entire voyage is wasted due to missing information and due to the lack of communication when the vessel is outside cell phone or other communications tools’ reach. However, the representative of BWMS developer should not at all interfere with the system operation to guarantee independent test runs of fully developed BWMS. While the previous Guidelines G8

amendments were discussed, it became clear that the independence of the tests is a crucial point, and IMO agreed on a stronger statement. Now the BWMS Code states that shipboard testing of BWMS shall be conducted by the test facility, independent of the BWMS manufacturer (see BWMS Code, Annex, paragraph 2.4), with the system being operated and maintained by the ships' crew as per the operation, maintenance and safety manual (see BWMS Code, Annex, paragraph 2.7). This means that no BWMS manufacturer is permitted to join the test voyages and neither to visit the ship over the six-month testing period, other than for routine or planned maintenance work, which has to be documented properly (see BWMS Code, Annex, paragraph 2.8.11.5).

2.2.7 Control Experiment

It was agreed at IMO that to evaluate BWMS performance, in parallel to the test with BWMS, a control experiment needs to be conducted with untreated water during which a certain number of organisms need to survive. This way, it can be documented that the organisms in the treated water are treated by BWMS and did not die because of the storage time and conditions between ballast water uptake and discharge. This requirement was formerly implemented in both the land-based and shipboard tests.

However, this requirement causes problems, especially in shipboard tests, as certain countries today have regulations that do not permit the discharge of unmanaged ballast water so that the control test water cannot be discharged in ports of such countries. This will also be the case for the signatory countries of BWM Convention as the convention entered into force. Consequently, in these countries, no shipboard test would have been possible, and it was therefore recommended to add a waiver for this aspect so that in consultation with the Administration, the control experiment may either be dropped or on an

exceptional basis, control water can be discharged in a port (Gollasch and David 2015).

It should also be noted that on certain vessels, the control experiment requirement caused substantial problems because during the discharge experiments, the living organisms in the control water “contaminated” the treated water. This means that living organisms were found in the treated water, which most likely originated from the control experiment (Gollasch and David 2015).

Noting the above-stated concerns, IMO agreed to drop the control tests during shipboard testing. However, for land-based testing, these tests are still required (see, e.g., BWMS Code, Annex, paragraph 2.43.1.2).

2.2.8 Abiotic Conditions

To evaluate the extent to which the set values, e.g., Total Suspended Solids (TSS), in the previous G8 Guidelines and the new BWMS Code as well as the ETV protocol (2010) requirements were met, we compared these requirements with our test results (Chapter “Testing Ballast Water Management Systems: Challenge Water Conditions During More Than 100 Test Voyages”). These requirements were set for land-based BWMS tests with the aim of challenging BWMS with water conditions that reflect conditions in ports. Our shipboard test results show that the level of compliance with IMO and ETV challenge water requirements varies with salinity. In summary, the marine water IMO TSS requirements were met well, which means that the challenge water requirements well reflect the ballast water uptake conditions of vessels. However, ETV TSS requirements for marine water are not that well met indicating that these requirements might represent particularly challenging conditions. In brackish water, IMO TSS requirements are poorly met. This indicates that especially IMO TSS requirement of >50 mg/L for brackish water is set to a level which is remarkably high. This is also

the case for the IMO TSS freshwater requirement, where none of our sampling events met the IMO requirements of the previous Guidelines G8 and new BWMS Code (Gollasch and David 2021).

It should be noted that especially the TSS content in certain ports is much higher than what IMO and ETV require. One example is the freshwater, inner estuarine Port of Hamburg (Germany), where the long-term mean TSS content is above 50 mg/L, which matches well with IMO challenge water requirements, and this is already more than double of what is required by the ETV Protocol. However, TSS content of the water between Hamburg and the North Sea, which is of brackish condition, frequently reaches concentrations above 300 mg/L, with extremes even above 600 mg/L (Gaumert 2002; Bergemann 2004). First et al. (2014) also documented that TSS values in marine waters of different regions on many occasions were well above the IMO and ETV Protocol challenge water requirements. This means that in nature, the TSS load BWMS need to manage may be much higher than during the BWMS certification tests. If and what problems this may cause will only become known when BWMS are more in routine use. For more details regarding other abiotic parameters, please see chapter “Testing Ballast Water Management Systems: Challenge Water Conditions During More Than 100 Test Voyages”. TSS and other water parameter requirements were briefly discussed during IMO debates on Guidelines G8 amendments, but it was agreed that further reviews of port water environments are needed before changes to these values can be concluded.

2.2.9 Biotic Conditions

In our samples, a much higher viable phyto- and zooplankton organism count was observed in freshwater compared to brackish or marine waters, which makes BWMS tests here more challenging (see chapter “Testing

Ballast Water Management Systems: Challenge Water Conditions During More Than 100 Test Voyages", Gollasch and David 2021). In consequence, BWMS only tested in marine and brackish waters may not meet the D-2 standard when freshwater has to be handled.

Regarding the biological challenge water conditions for shipboard BWMS tests, it is interesting to note that this was almost always met for zooplankton in our tests. However, in ca. 20% of the sampling events, the phytoplankton requirement was not met, indicating that the challenge water standard for phytoplankton is stronger compared to zooplankton. We recommend increasing the zooplankton requirement so that both biological challenge water standards are at a similar level. However, IMO noted that more research results may provide evidence to renegotiate certain aspects of the BWMS Code and the BWM Convention. To generate knowledge, IMO agreed to launch an Experience Building Phase (EPB) to promote research in this field, and this is now ongoing (see chapter "Introduction: Update of BWM Book First Edition").

The D-2 standard also refers to Cholera bacteria. It is understood that in certain regions of the world, Cholera is of great concern. It was further documented that Cholera bacteria occur in ocean waters and also that they are transported in ballast water of vessels (Ruiz et al. 2000). However, during more than 120 shipboard tests we have conducted, these bacteria were never found; therefore, we would recommend changing this requirement to be limited to the ballast water uptake areas where a World Health Organization (WHO) alert for the presence of Cholera is issued. As already stated above, IMO agreed that further research is needed before the D-2 standard may be changed.

3 Further Amendments of the Previous Guidelines G8 as Now Addressed in the BWMS Code Adopted in 2018

The above-stated recommendations of Gollasch and David (2015) were considered in a correspondence group aiming to prepare amendments of the previous Guidelines G8. Major amendments were made as a result of the discussions. In addition to the amendments listed above, the following selected changes to the previous Guidelines G8 were agreed:

- more comprehensive quality control and quality assurance requirements of the test facilities are required (see, BWMS Code, Annex, paragraphs 2.2 and 2.3);
- increased temperature regimes for tests (between 0 °C and 40 °C), subject of an assessment verified by BWMS certifying Administration (see, BWMS Code, Annex, paragraph 2.46);
- a higher number of (sub)samples has to be analyzed (see, e.g., BWMS Code, Annex, paragraph 2.8.6.2.2 and 2.43.2.2);
- the use of standard test organisms is permitted as supplementary test organism, but their use has to result in challenging conditions and robust test results (see, BWMS Code, Annex, paragraph 2.32);
- a new definition of viability was agreed so that this may be established by assessing the presence of one or more essential characteristics of life, such as structural integrity, metabolism, reproduction, motility or response to stimuli (see BWMS Code, Annex, paragraph 4.6);
- the minimum holding time between the ballast water uptake and discharge in land-based tests was changed from “5 days” to “shorter or longer than 5 days” (see,

e.g., BWMS Code, Annex, paragraph 2.14). For shipboard tests, it is stated that BWMS shall be effective in meeting the D-2 standard on short and long voyages (i.e., short- and long-time intervals between treatment and discharge) (see BWMS Code, Annex, paragraph 4.2);
- it was agreed that the shipboard tests cannot be conducted back-to-back, but that the tests must be suitably separated across the six-month testing period (see BWMS Code, Annex, paragraph 2.8.9);
- BWMS operational limits should be clearly documented on the Type Approval Certificate. For each such parameter, a low and/or a high value should be given (see BWMS Code, Annex, paragraph 5.5);
- type-approved BWMS have to have a suitable self-monitoring system that will monitor and record sufficient data to verify the correct operation of the system. Further, all system alarms should be stored and made available for inspection (see, e.g., BWMS Code, Annex, paragraph 5.1);
- it was also agreed that when a bypass or override was used in emergency situations, this should activate an alarm, and the event should be recorded by the control equipment (see BWMS Code, Annex, paragraph 7.2).

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4 IMO Versus USCG BWMS Test Requirements

Additional BWMS test requirements of the USA need to be met and are outlined in the ETV Protocol of 2010. The key differences between the BWMS Code (IMO 2018) and the requirements expressed in the ETV Protocol (2010) are that the ETV protocol is more specific. The ETV protocol further requires that more abiotic water parameters have to be measured compared to IMO requirements. In addition, to ensure quality control, more blanks and

positive as well as negative control samples have to be analyzed according to ETV, and this protocol is more specific on the methods to be used by stating required sensitivity of the instruments to be used and their detection limits. ETV further states the maximum holding time between sample taking and analysis and it requires sample processing and sample preservation details.

To ensure independency of the test facility, the BWMS Code requires that the test facility should not be owned or affiliated with the manufacturer or vendor of any BWMS, by the manufacturer or supplier of the major components of that equipment, or by the owner or operator of ships that would be required to use such equipment. ETV addresses this by a review process of the test facility and its work program to ensure independency and that certain work standards are met. A positive evaluation results in the approval of the test facility as “Independent Laboratory”. Currently, six such laboratories are recognized by USCG, and they are in Germany, the Netherlands, Norway, the Republic of Korea and the United Kingdom.[1]

4.1 Key Differences in Land-Based Requirements

The similarities and differences in IMO and USCG challenge water requirements are presented in Table 1. The salinity requirements may be more difficult to achieve when natural waters have little variability. The Revised G8 Guidelines incorporated the addition of fresh water, or saline water to decrease or increase salinity may be an option, but then the effect, besides that of dilution, on the organisms must be validated. USCG prescribes water temperatures during tests of 4 to 35 °C, where IMO has no requirements, but it is unlikely that temperatures beyond these extremes are encountered at test facilities. The chemical constituents POC and DOC do not differ much

between IMO and USCG. On the contrary, the minimum TSS concentration is only 24 mg/L for the USCG, which is just half as IMO's 50 mg/L so that it is more challenging for certain BWTSs (Jang et al. 2020).

Table 1 Similarities and differences in IMO and USCG challenge water requirements

	Land-based challenge water requirements		
Variable	**IMO**	**USCG**	**Unit**
Salinity	<1, 10–20, 28–36	<1, 10–20, 28–36	PSU
Temperature	No	4 to 35	°C
TSS (high)[a]	>50	≥24	mg/L
MM (high)[a]	No	≥20	mg/L
POC (high)[a]	>5	≥4	mg/L
DOC (high)[a]	>5	≥6	mg/L
UV-T	No	No	%
Organisms >50 µm (≥3 phyla, ≥5 species)	≥100,000	≥100,000	$/m^3$
Organisms 10–50 µm (≥3 phyla, ≥5 species)	≥1000[b]	≥1000	/mL
Organisms <10 µm	No	No	/mL
Total bacteria	≥10,000	≥1000	/mL
E. coli	No	No	/mL
Enterococci	No	No	/mL
Vibrio cholerae O1 + O139	No	No	/mL

[a](High) meaning highest concentration, in low and medium salinity ranges

[b]IMO BWM.2/Circ.61 allows the use of the MPN and motility assessment of living viable organisms, whereas the USCG does solely allow microscopy with Fluorescein diacetate and 5-Chloromethylfluorescein diacetate

(FDA/CMFDA) staining as prescribed in ETV protocol (ETV protocol 2010)

Fortunately, the organism concentrations are largely the same for both IMO and USCG, with only a difference in the concentration of total heterotrophic bacteria. Even for coastal test facilities with relatively eutrophic waters, the concentrations of organisms less than 50 µm in minimum dimension and greater than or equal to 10 µm in minimum dimension and organisms greater than or equal 50 µm in minimum dimension can be below the requirements. This implies that challenge water needs to be enriched with natural organisms obtained by filtration of ambient water, large volumes of water need to be incubated and enriched with nutrients to stimulate autotrophic growth, or the addition of cultured organisms. A popular easy-to-culture species is the marine green alga *Tetraselmis suecica*. However, the minimum dimension of this species is close to 10 µm, with part of the population, depending on growth conditions, below 10 µm. Testing under IMO conditions may infer the addition of cultured heterotrophic bacteria (Peperzak 2023). The indicator microbes do not need to be added and are often not present in non-polluted waters, which means that testing them before and after treatment is rather useless. If the IDEXX Most Probable Number (MPN) method is used, for e.g., enterococci, positive findings may be suspected due to other species than the target one that are able to grow in the enterococci-specific culture medium (Peperzak and van Bleijswijk 2021).

Whether or not the MPN and motility assessment is allowed in testing BWMS is a seemingly minor difference between USCG and IMO requirements. However, it has had a great impact on the development of UV-based BWMS. Typically, a lower UV dose is required to render organisms incapable of reproducing (measured with MPN) compared to the higher UV dose needed to inactivate their esterase

enzymes (measured by FDA/CMFDA double staining technique). This means that UV manufacturers typically offer two operational modes of their BWMS: an IMO mode and a USCG mode.

4.2 Key Differences in Shipboard Requirements

ETV requires five consecutive valid shipboard tests, while the BWMS Code states that three are needed. Both instruments state that the testing period shall stretch over not less than six months with BWMS in routine operation.

Other differences refer to the voyages during the shipboard testing. In ETV, no vessel voyage is required between ballast water uptake and discharge, but ETV tests are required to be performed in different climate zones. In contrast, the BWMS Code requires a vessel voyage between uptake and discharge sampling events and does not specify the climate zones in which the tests have to be conducted.

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5 Conclusions

The earlier version of the Guidelines G8 requirements was considered not representing enough challenging test conditions for areas where ballast water is taken up to ensure proper BWMS performance. Therefore, BWMS that have received type approval may be found non-compliant if operated in more challenging water conditions as BWMS was exposed to during the type approval tests. This was one of the key reasons to amend the previous Guidelines G8 so that tests better reflect the real-world ballast water uptake conditions, and further that the type approval certificates should clearly identify the limitations of the BWMS operation according to the tests conducted.

The test requirement amendments as stated above are expected to deliver better and more reliable BWMS test results to consequently have more reliable BWMS installed

on vessels in the future. In turn, this would result in better protection of the natural environment, human health and resources. In addition, this will help to avoid disruption of vessels' commercial activities in cases of failed compliance due to improperly performing BWMS.

With stronger test requirements, it is hoped that BWMS are tested at or near real-world ballast water uptake conditions so that the D-2 standard is met under a wide range of conditions. Additional and stronger test requirements are in the interest of all involved, including (a) the ship-owner to have a better guarantee that BWMS is fit for purpose, (b) BWMS manufacturer to have a widely applicable BWMS and (c) the Administration to have greater confidence in the issued certificates.

We note that water conditions may occur with, e.g., the content of TSS even 10 times or more higher than the required land-based challenge water. However, we consider these as extreme events, which are unlikely to be handled by a BWMS routinely. Should BWMS fail under such conditions, contingency measures become relevant (see chapter "Introduction: Update of BWM Book First Edition").

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Footnotes

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M. David, S. Gollasch (eds.), *Global Maritime Transport and Ballast Water Management*, Invading Nature - Springer Series in Invasion Ecology 16
https://doi.org/10.1007/978-3-031-48193-2_3

Testing Ballast Water Management Systems: Challenge Water Conditions During More Than 100 Test Voyages

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Abstract
Ballast water management systems (BWMS) are rigorously tested in land-based and shipboard settings, according to requirements outlined in the former G8 Guidelines of the International Maritime Organization (IMO). Noting doubts that the water conditions to challenge BWMS as stated in G8 may not be challenging enough to represent all port water conditions worldwide, this guideline was revised at IMO in 2016 to make G8 better fit for purpose, and the instrument was made mandatory as BWMS Code in 2018. This contribution summarizes the intake water conditions we observed during >300 samples taken during >100 shipboard BWMS performance tests during 12 years. The data presented include the abiotic water conditions (i.e., temperature, salinity, TSS and POC) and the counts of viable organisms in the two size classes addressed by the Ballast Water Performance Standard (Regulation D-2) of the IMO Ballast Water Management Convention. Our data showed how close IMO challenge water requirements are to what was observed in nature. In addition, we compared our results with the test requirements of the US BWMS test protocol. Based on our results, further recommendations for BWMS Code improvements were included. These recommendations refer to the challenge water conditions in performance tests of BWMS, which were kept unchanged during the G8/BWMS Code revision(s). One of our recommendations is to increase the required concentration of zooplankton organisms in the challenge water during shipboard tests to better reflect the natural zooplankton concentrations.

Supplementary Information
The online version contains supplementary material available at https://doi.org/10.1007/978-3-031-48193-2_3.

Keywords Ballast water management systems – Challenge water – Shipboard testing – Species introduction

1 Introduction

Shipping is a major species introduction pathway with ballast water and biofouling being the prominent vectors (Gollasch 1996; Flagella and Abdulla 2005; Minchin et al. 2005; Katsanevakis et al. 2016). Introduced species caused drastic negative impacts to the environment, ecology and also to human health (e.g., Hayes and Sliwa 2003; Pimentel et

al. 2005; Katsanevakis et al. 2014; Gallardo et al. 2015). To address the species introduction pathway ballast water, the International Maritime Organization (IMO), the United Nations body to deal with shipping, adopted the International Convention for the Control and Management of Ships' Ballast Water and Sediments (BWM Convention) (IMO 2004). This convention sets limits to viable organisms in ballast water discharges in the Ballast Water Performance Standard, Regulation D-2 (hereafter D-2 standard), i.e., "ships conducting ballast water management in accordance with this regulation shall discharge less than 10 viable organisms per cubic metre greater than or equal to 50 micrometres in minimum dimension and less than 10 viable organisms per millilitre less than 50 micrometres in minimum dimension and greater than or equal to 10 micrometres in minimum dimension". The D-2 standard further limits the discharge of so-called indicator microbes in ballast water discharges.

It was recognized that the discharge limits of viable organisms may only be met by some kind of ballast water treatment (Lawrence and Cordell 2010; Casas-Monroy et al. 2015). Various water treatment technologies were considered by manufacturers of ballast water management systems (BWMS). Most BWMS consist of a combination of mechanical, physical, chemical and/or biological processes to eliminate or inactivate organisms in ballast water (Tsolaki and Diamadopoulos 2010; Lloyds Register Report 2012; Balaji et al. 2014; David and Gollasch 2015; Stehouwer et al. 2015; Bai et al. 2016, 2018; Ren et al. 2016; Batista et al. 2018; David et al. 2018). BWMS need to be rigorously tested in land-based and shipboard settings to document their performance in different water conditions. The test requirements were in the past outlined in IMO G8 Guidelines (IMO 2008b, 2016) and are now described in the BWMS Code (IMO 2018). For shipboard tests, the G8 Guidelines, now the BWMS Code, require(d) to document water conditions before a BWMS was applied (challenge water). The abiotic parameters to be measured for shipboard testing include Total Suspended Solids (TSS), Particulate Organic Carbon (POC), temperature and salinity. In addition, the concentration of viable organisms has to be documented according to higher taxonomic groups and in two organism size classes, as addressed by the D-2 standard.

As the focus of this manuscript was to document the abiotic conditions and concentration of viable organisms of the challenge water during ballast water uptake, on purpose we excluded the results of the samples taken after treatment when the ballast water was discharged.

According to Guidelines G8 of 2008 (IMO 2008b), the shipboard BWMS tests included a control experiment in which the organism's survival without BWMS application was documented. This means that for most of the sampling events, we took one set of samples of untreated water before BWMS and a second sample set of untreated water when the control tank was filled. The revision of Guidelines G8 in 2016 resulted in the deletion of the control experiments for shipboard testing, and therefore the data considered for this review were generated during the validity of the Guidelines G8. It may be of interest that when the G8 Guidelines were modified another time in 2018, they were set up in a mandatory nature as BWMS Code (IMO 2018).

What separates our study from most other biological studies is that we document (a) the concentration of organisms per water volume rather than the biomass, Chlorophyll content or ocean surface color (e.g., Gowen et al. 2008; Loebl et al. 2009; Kostadinov et al. 2017), (b) we documented the concentration of viable organisms thereby ignoring dead individuals or parts of organisms, (c) we documented the organisms by their size in minimum dimension, (d) we did not focus on a certain taxon or group of taxa only, but documented all viable organisms found, (e) we enumerated phytoplankton and zooplankton of the same water body sampled so that we have a direct comparison of these two groups of organisms, (f) we took samples using in-line sampling points in the vessels ballast water pipework and (g) we sampled ballast water during uptake, whereas most other studies sampled ballast water at the end of a voyage or during discharge (e.g.,

Locke et al. 1993; Gollasch 1996; Bailey et al. 2005; David et al. 2007; Seiden et al. 2010; Soleimani et al. 2017).

2 Sampling Event Details

The ballast water uptake samples were taken during shipboard performance tests of BWMS for 18 manufacturers based in Canada, Denmark, Finland, France, Germany, Greece, Norway, Singapore, South Africa, United Kingdom and United States of America. More than 100 test voyages were carried out between July 2005 and March 2017. We followed the IMO sampling requirements as stated in the G2 Guidelines (IMO 2008a) and G8 (IMO 2008b). We excluded sampling events after March 2017 as from this time onward we changed the sampling approach and the sample analysis to meet the new requirements in the 2016 version of the G8 Guidelines, the BWMS Code and also the USCG test requirements (ETV Protocol 2010; IMO 2016, 2018; US GPO 2017).

Overall, 328 ballast water uptake sampling events (challenge water and control experiments) occurred during the >100 test voyages, which means that on some test voyages, several sampling events were conducted (see Supplementary Table 1).

The number of sampling events per year ranged from 3 to 64 and the busiest years with more than 50 sampling events occurred in 2009 and 2010 (Fig. 1). Sampling events were conducted in all months with a peak in September (Fig. 2).

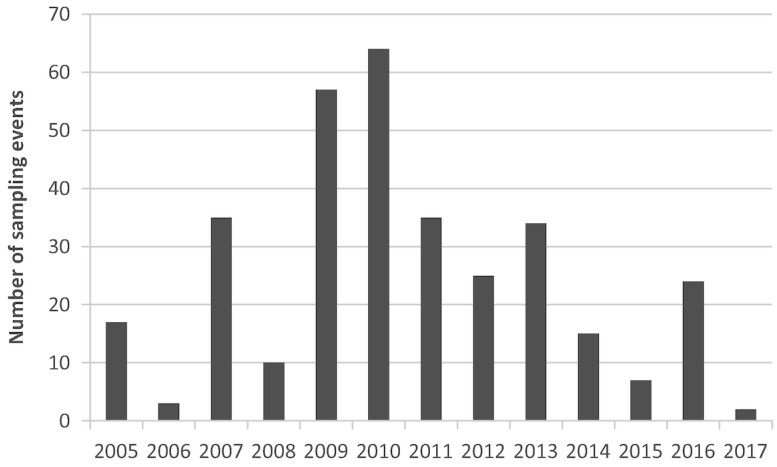

Fig. 1 Number of sampling events per year

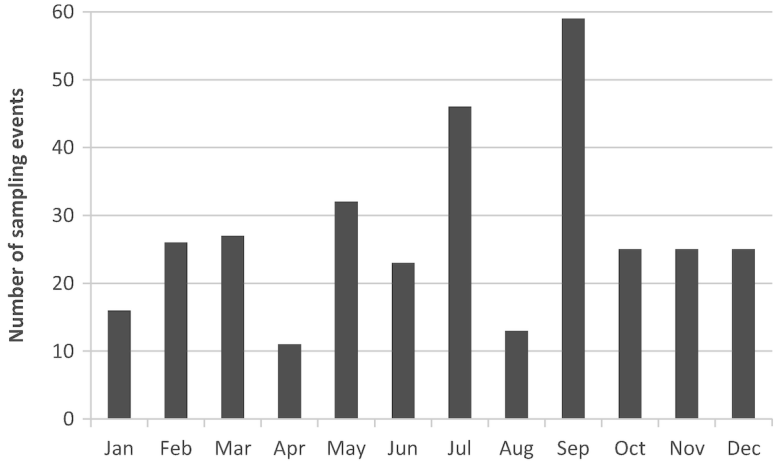

Fig. 2 Number of sampling events in all years per month

The sampling events were further grouped in meteorological seasons (Fig. 3). For the northern hemisphere, Spring was set as from 1 March to 31 May, Summer from 1 June to 31 August, Fall from 1 September to 30 November and Winter from 1 December to 28 February. Sampling events of the southern hemisphere were added to the relevant season in the northern hemisphere so that a southern hemisphere sampling event in Spring was added to the northern hemisphere as in Fall. Almost all samples were taken in waters on the northern hemisphere, with only 10 samples from the southern hemisphere (see Supplementary Table 1). Sampling events occurred in all seasons, but predominantly in Fall (Fig. 3).

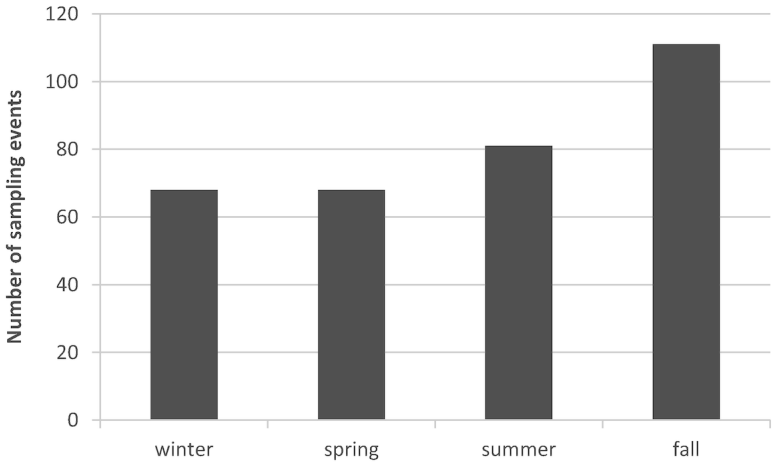

Fig. 3 Number of sampling events in all years per season

Sampling events occurred along coasts of all five permanently inhabited continents (Fig. 4) in 22 different Large Marine Ecosystems (LMEs). With 264 samples, the temperate regions dominate over the 64 samples taken in the tropics. Approximately two-thirds of the sampling events occurred in north-western Europe (LME 22–25), followed by sampling events in southeast Asia (31 samples in LME 36), the Yellow Sea (25 in LME 48) and the Arabian Sea (14 in LME 32). In other LMEs, less than 10 sampling events were conducted. Most sampling events occurred in coastal areas, but in ca. 10% of the samples the sampling event location was inland, i.e., inland ports in Europe and the North-American Great Lakes (Fig. 5).

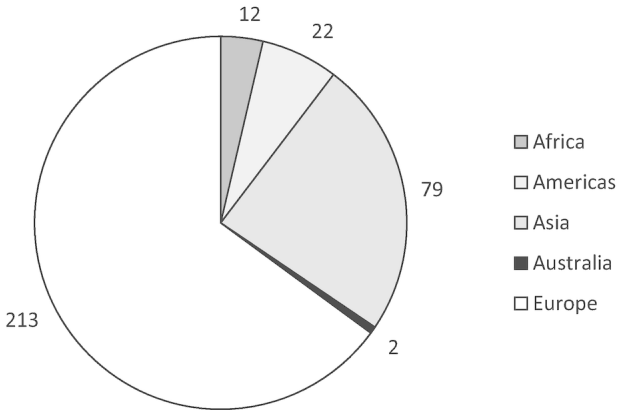

Fig. 4 Number of sampling events per continent

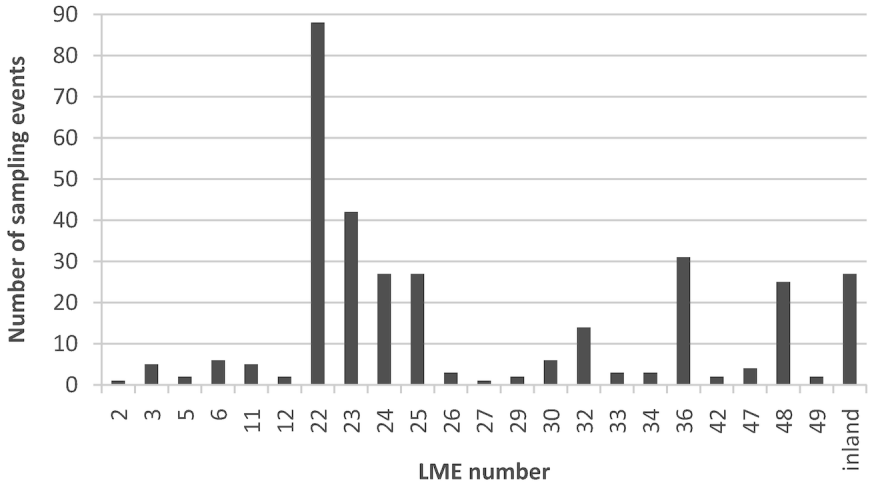

Fig. 5 Number of sampling events per LME

In 172 cases, the samples were taken in ports while the test vessel was alongside a pier. The 156 sampling events conducted during navigation were performed off the coast in regional seas and also when crossing oceans (see Supplementary Table 1).

2.1 Sampling Point

The sample water to be analyzed was taken during ballast water uptake via a sampling port in a sampling point located in the main ballast water pipework. The sampling points were mostly located in the vessel's pipework before BWMS or in the pipework of the control experiment. The sampling port was L-shaped with an opening directed toward the water flow and located in the center of the vessel's ballast water pipe (Fig. 6).

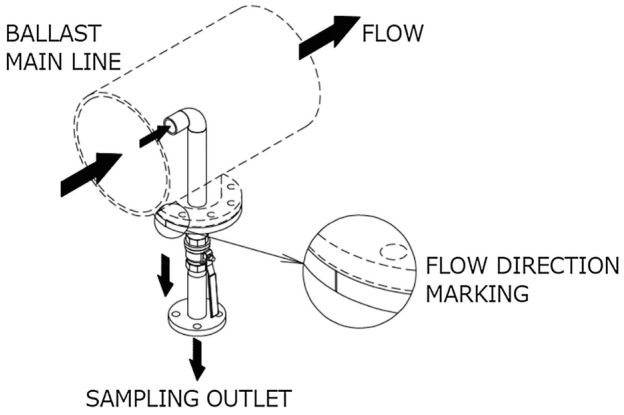

Fig. 6 Design of an in-line ballast water sampling port (Courtesy of Kuraray)

2.2 Sample Volumes

TSS and POC samples were taken as sub-samples of the >10 L phytoplankton samples (see below). The 10 L phytoplankton sample bucket was mixed well and a 1 L sample bottle was filled. Approximately 200–500 mL of this water was pumped through a GF/C filter (0.45 µm, Whatman, Sigma-Aldrich, St. Louis, USA) for later analysis using a Millipore stand (Merck Millipore, Billerica, USA). The water volume filtered was related to the particle and biological content of the water. In water with high concentrations of organisms and rich sediment load, the filter got clogged so that only 200 mL was filtered; in other occasions, without these hindering conditions, samples with a volume of 500 mL were processed.

For phytoplankton samples >10 L of unfiltered water were collected, and this was done as multiple discrete samples during the entire ballast water uptake operation. For this purpose, a measuring cup was filled multiple times (every few minutes or every 100 L passing through the sampling system used for zooplankton samples (see below), as indicated by the flow meter used (Bürkert, Hannover, Germany)). Buckets with lids were used to collect these samples, and the lid was put back on the bucket after emptying the measuring cup into the bucket to avoid sample contamination from the outside.

Phytoplankton samples were either analyzed after the test voyage on land or directly after the sampling event on board. For the land-based sample analysis, a 100 mL bottle was filled with the well-mixed water of the 10 L bucket and stored slightly cooler than the ambient water conditions but avoiding a temperature shock (Gollasch and David 2018). This means that in temperate areas the sample was stored in a fridge and in the tropics at room temperature, but without light exposition. For the transport to the land-based laboratory, cooling elements and Styrofoam boxes were used.

For on-board processing, after mixing of the 10 L sample bucket, a 1 L bottle was filled for direct analysis. In minimum three times 1 mL sub-samples of the 1 L sample were analyzed by using a Sedgewick-Rafter chamber with a 1/1000 square division (Camlab, Cambridge, UK) and a Zeiss epifluorescence microscope (Oberkochen, Germany). The full volume of the multiple 1 mL sub-samples was analyzed unless the total concentration of viable organisms was high (>100 org./mL). In these cases, parts of the Sedgewick-Rafter chamber were analyzed, and the organism concentration per mL was calculated based on the sub-sample volume analyzed.

For zooplankton analysis, the water was, during almost all sampling events, sampled over the entire ballast water uptake time as one, time-integrated sample. In rare cases, samples were taken in sequences in the beginning, middle and end of the pumping event. A comparison of sampling results of sequential sampling events with samples taken over the entire pumping event was published elsewhere (Gollasch and David 2017). Each sequence was, in this study, handled as individual sampling event because in cases when the sampling occurred while the vessel was in navigation, she had traveled some distance so that the sequences would not have the same area of origin. When working in ports, e.g., the water current situation was changing between the sequential samples that were taken. We therefore considered all sequences as individual sampling events.

For all zooplankton samples, the Hydro-Bios Ballast Water Sampling Kit (Hydro-Bios, Kiel, Germany) was used (Fig. 7). This consists of a filtering net and removable cod-end with a mesh of 50 µm in diagonal dimension. It further includes a flow meter that the filtered water volume can be measured (Gollasch 2006). The plankton net was lowered into a sampling bin so that it sat in water as much as possible.

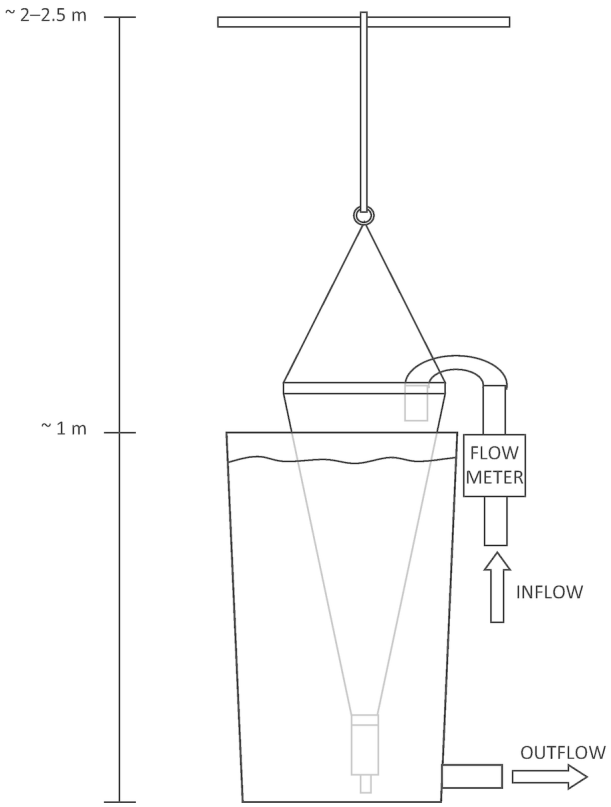

Fig. 7 Use of Hydro-Bios ballast water sampling kit and sampling bin (David 2013)

For the enumeration of zooplankton, the sample extracted from the plankton net was filled into a 1 L bottle. This sample was concentrated further to 100 mL using a mesh with holes no greater than 30 micrometers in diagonal dimension for an immediate on-board analysis. The full volume of the concentrated sample was analyzed, unless the total concentration of organisms was high (>100 organisms). For samples with high organism content, the organism concentration was calculated based on the sub-sample volume analyzed.

2.3 Measurement of Abiotic Parameters

TSS and POC samples were analyzed at the Royal Netherlands Institute for Sea Research (NIOZ), Texel, The Netherlands. Before boarding the test vessels, fiber filters (Whatman GF/C) were dried overnight at 500 °C, weighed and put in numbered Petri dishes, which were stored in plastic bags. After the water was filtered on board, the filter was rinsed three times with 10 mL distilled water and the filter was put back in its original Petri dish. Thereafter, the filters were frozen at ca. –20 °C (in the vessels deep freezer) and kept frozen until analysis. During transport to NIOZ, the samples were stored in a Styrofoam box with frozen cooling elements. For TSS analysis at NIOZ the filters were immediately put in a dry oven and dried at 60 °C overnight. Thereafter, the filter was weighed, and the before and after weights were compared as TSS measurement. To analyze for POC, the same filter was combusted overnight at 500 °C and allowed to cool down in a vacuum desiccator and weighed again.

For salinity measurements, a calibrated electronic instrument was used (WTW, Weilheim, Germany), and the salinity was measured during the sampling process at the sampling point. At the same time, the water temperature was measured with the same instrument. Both measurements were done approximately 10 min after the start of the vessel’s ballast water pump.

2.4 Viability Determination of Organisms

The organism viability was determined as per IMO agreement, i.e., “viability may be established by assessing the presence of one or more essential characteristics of life, such as structural integrity, metabolism, reproduction, motility, or response to stimuli” (IMO 2016), which means that one way of determining viability is to identify that organisms are living.

2.4.1 Phytoplankton

Phytoplankton analysis was carried out at NIOZ either using a Beckman Coulter EPICS-XL-MCL flow cytometer (Brea, USA) or a Becton Dickinson FACSCanto II flow cytometer (Franklin Lakes, USA).

Two different methods were used to distinguish viable phytoplankton from detrital material and zooplankton, and either one of the methods was used to process the phytoplankton samples.

In method 1, the flow cytometer was used to determine the concentration of organisms in a sample per size class and per the presence of chlorophyll autofluorescence. To distinguish viable organisms from dead material, samples were also stained with SYTOX Green (Veldhuis et al. 1997, 2001; Veldhuis and Kraay 2000). This nucleic acid-specific dye only stains DNA of cells with a compromised cell membrane, i.e., only dead cells are stained (Veldhuis et al. 2001; Casotti et al. 2005; Peperzak and Brussaard 2011). In addition, the photochemical efficiency of photosystem II, an indicator of the “health” condition of phytoplankton cells, was assessed using Pulse-Amplitude Modulation (PAM) fluorometry (Schreiber et al. 1993). This parameter gives an indication of the photosynthetic activity of the phytoplankton community, thereby documenting living algae (Stehouwer et al. 2010). In summary, the flow cytometer gave the concentration of (intact) cells and the PAM instrument confirmed the viability as a bulk measurement. The Water-PAM used was manufactured by Walz, Effeltrich, Germany.

In method 2, the organism viability was documented with the addition of vital stains to the sample, i.e., fluorescein diacetate (FDA) (Thermo Fisher Scientific, Waltham, USA) and 5-chloromethylfluorescein diacetate (CMFDA) (Thermo Fisher Scientific). FDA and CMFDA are cell-permeant stains which serve as viability probes to measure enzymatic activity by means of fluorescence in intact phytoplankton cells. Cell integrity is needed for the intracellular retention of the fluorescent product. The stained samples were analyzed with a Zeiss epifluorescence microscope (Oberkochen, Germany) using a fluoresceinisothiocyanate (FITC) narrow pass filter with a magnification >40 and a Sedgewick-Rafter counting chamber.

2.4.2 Zooplankton

For zooplankton, the viability assessment was made based on organism movements or organ activity, such as heartbeats or digestive tract activity, and by their integrity, i.e., only complete organisms were considered as viable. The samples were analyzed on board within 6 hours after the sampling event was terminated. Each zooplankton organism found was observed individually, and in case no movement or organ activity was observed, the organism was carefully poked with a needle to stimulate movement. Non-moving organisms after poking were considered as dead, i.e., were not counted.

Viable zooplankton were counted using a stereomicroscope (Müller, Erfurt, Germany) with at least 10x magnification. The viable organisms were counted as per higher taxonomic groups.

A Hydro-Bios counting tray was used for zooplankton counting. This is a modified Bogorov chamber with disconnected canals avoiding the serpentine layout to avoid organism movements within the canal (Fig. 8) (Gollasch 2006).

Fig. 8 Modified Bogorov counting chamber

2.5 Organisms' Minimum Dimension

The organism size needs to be documented in minimum dimension (IMO 2008a). As agreed at IMO, minimum dimension means the minimum body dimension of an organism ignoring, e.g., the size of spines, flagellae or antenna. Therefore, the minimum dimension should be the smallest part of the "body", i.e., the smallest dimension between the main body surfaces of an individual when looked at it from all perspectives. For spherical shaped organisms, the minimum dimension should be the spherical diameter (IMO 2008a). In summary, for the measurement of the minimum dimension, the smallest visible body axis of an organism was identified and the smallest "body" part on this axis was measured. It should be noted that especially for the phytoplankton analysis using a Sedgewick-Rafter counting chamber covered with a glass lid, the organisms could not be moved with a needle to identify the smallest axis. We therefore used the term smallest "visible axis". For the flow cytometer analysis, the phytoplankton organism minimum dimensions were measured relative to 10 µm and 50 µm standard fluorescent beads (Flow-Check Fluorospheres, Beckman Coulter #660539, Brea, USA). For the microscopic analysis, a Zeiss camera was used with software to measure the objects. In addition, the Sedgewick-Rafter counting chamber grid line width was measured and used as size indication, which the analyst had in vision constantly.

The same 50 µm beads were used to identify the zooplankton organisms ≥50 µm in minimum dimension. A low concentration of beads was added to the sample so that the analyst had the beads in the vision when searching the sample for viable zooplankton. Alternatively, a piece of the 50 µm net (measured in diagonal dimension) was placed below the Hydro-Bios counting chamber so that the analyst had the size indication constantly in vision.

2.6 Taxonomy

A determination to higher taxonomic groups was only conducted for zooplankton and this was done according to the taxonomic groups as described in Newell and Newell (1963). Phytoplankton were not taxonomically determined as the methods applied to assess the required phytoplankton viability did not permit a taxonomic analysis at the same time. Flow cytometers can only distinguish taxonomic groups on a very broad scale according to the typical adsorption spectrum. For taxonomic analysis, the identification under bright field illumination would be needed in addition, but the time before the viability stain starts leaking from the cells would have been too short to analyze for both.

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3 Results

Not all parameters were measured during all sampling events (see Supplementary Table 1). However, the zooplankton analysis was always carried out so that 328 zooplankton counts are available. For phytoplankton, 271 analyses were prepared and for temperature 295 measurements occurred, for salinity 277, for TSS 175 and for POC 167.

3.1 Abiotic Factors

TSS content in the samples ranged from 2.0 mg/L in minimum to 176.9 mg/L in maximum, with a mean value of 23.2 mg/L. The TSS difference for sampling events in ports (125 samples) and at sea (50 samples) was marginal (Table 1).

Table 1 TSS content of all sampling events according to the uptake water location inside ports or during navigation

Uptake location	Quality	Amount [mg/L]
Inside port (125 samples)	Mean	22.1
	Minimum	2.0
	Maximum	176,9
In navigation (50 samples)	Mean	26.0
	Minimum	2.5
	Maximum	175.0

The most frequently documented TSS content was in the weight class 0 to 25 mg/L in 128 sampling events. Values above 50 mg/L were only found in 15 sampling events, of which 5 events were above 100 mg/L (Fig. 9).

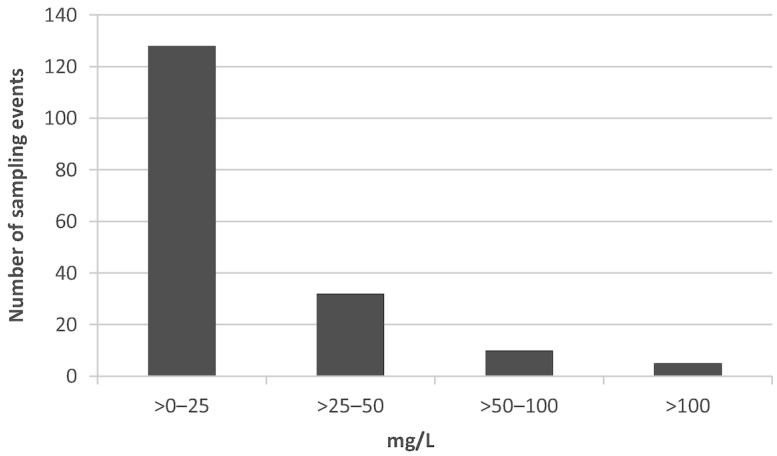

Fig. 9 Number of TSS measurement results of all sampling events in weight classes

The amount of POC in the samples ranged from 0.1 mg/L to 32.4 mg/L, with a mean value of 7.7 mg/L. In contrast to the TSS values, the POC values were different for the inside port and during navigation samples. The data in Table 2 show that the mean POC values during navigation were approximately half of the inside port values and the maximum POC values in a port were approximately 30% higher compared to the maximum during navigation.

Table 2 POC content of all sampling events according to the uptake water location inside and during navigation

Uptake location	Quality	Amount [mg/L]
Inside port (124 samples)	Mean	8.7
	Minimum	0.1
	Maximum	32.4

Uptake location	Quality	Amount [mg/L]
In navigation (43 samples)	Mean	4.9
	Minimum	0.1
	Maximum	25.2

The frequency of POC measurements in weight classes is shown in Fig. 10. Most frequent values (71 sampling events) were between 0 and 5 mg/L. POC values in the highest weight class (>20–30 mg/L) occurred in 12 cases.

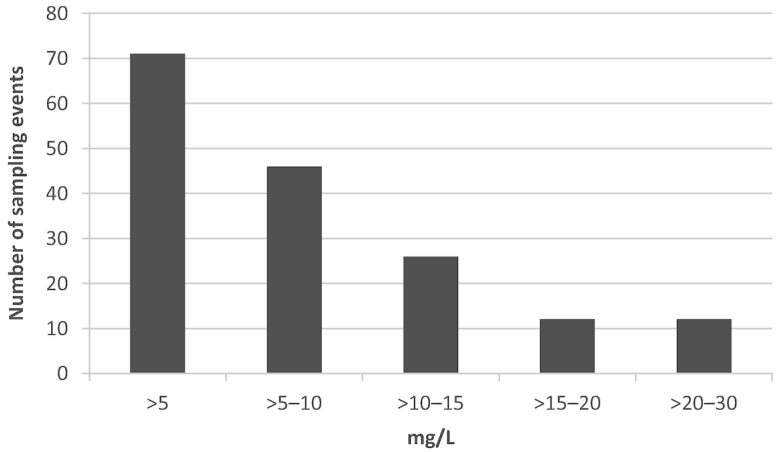

Fig. 10 Number of POC measurement results of all sampling events in weight classes

The temperature measurements ranged from 2.8 °C to 38.0 °C, with a mean value of 18.4 °C (Table 3). Most measured water temperatures were between 10 and 20 °C (Fig. 11).

Table 3 Temperature and salinity values of all sampling events

Parameter	Quality	Amount	
Temperature (295 samples)	Mean	18.4	°C
	Minimum	2.8	°C
	Maximum	38.0	°C
Salinity (277 samples)	Mean	26.2	psu
	Minimum	0.3	psu
	Maximum	43.3	psu

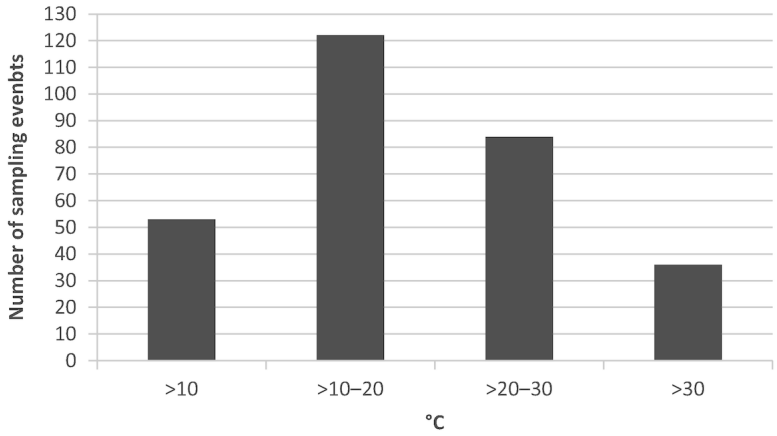

Fig. 11 Number of temperature measurement results of all sampling events

The salinity measured ranged from 0.3 psu to 43.3 psu with a mean value of 26.2 psu (Table 3). The salinity measurements were grouped as per the Venice System (1959). The most frequently found salinity in 162 cases was the euhaline (or fully marine) conditions. Salinities above 40 occurred rarely with 13 cases and limnetic salinities below 0.5 psu were found in 16 cases (Fig. 12).

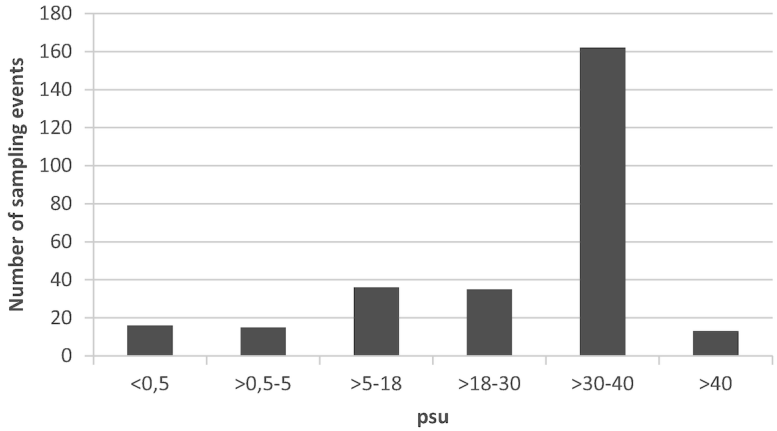

Fig. 12 Number of salinity measurement results of all sampling events. The salinity categories were chosen according to the Venice System (1959)

The water volumes sampled for phytoplankton and abiotic parameters were fixed as described above. However, for zooplankton samples, this parameter was widely fluctuating from 100 to 4459 L. The majority of samples had a volume of 1000–1499 L, which reflects IMO requirement that the samples should have a minimum volume of 1000 L (IMO 2008b). The high number of samples below 500 L is because for several BWMS, pre-full-scale-tests were conducted to confirm BWMS is correctly installed and working as intended. In many of these pre-full-scale-tests, the water volume filtered was lower than the minimum IMO requirement for full-scale tests (Table 4 and Fig. 13).

Table 4 The water volume sampled for zooplankton analysis of all sampling events

Parameter	Quality	Amount[L]
Water volume (328 samples)	Mean	1223.1
	Minimum	100.0
	Maximum	4459.0

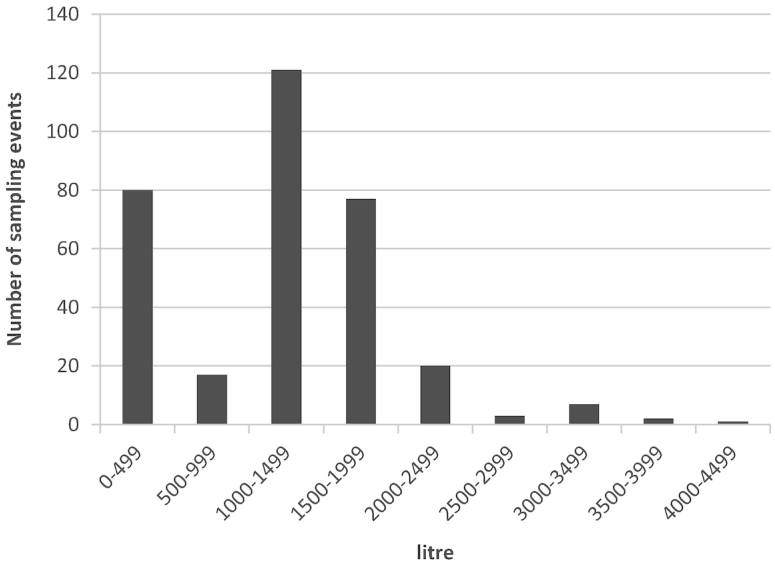

Fig. 13 Number of samples per water volume of all sampling events

3.2 Organism Concentrations

The D-2 standard separates two size classes of organisms at 50 µm in minimum dimension. One reason why IMO adopted these size classes was that the majority of phytoplankton species were believed to be smaller than 50 µm and the majority of zooplankton species are larger than 50 µm (IMO 2002). To address this separation, we report the biological results below, separated into phytoplankton and zooplankton.

3.2.1 Phytoplankton

The lowest concentration of viable algal cells was 0.8 per mL, the mean value was 822.5 and the maximum concentration was 20,924 viable cells/mL (Fig. 14).

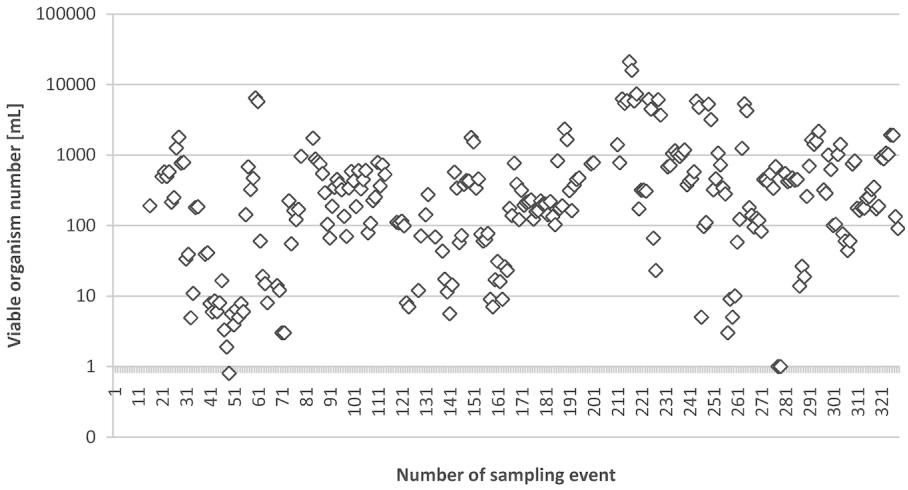

Fig. 14 Concentrations of viable phytoplankton cells per mL of all sampling events

The concentration of viable phytoplankton cells fluctuated according to the months during which the sampling events occurred, with the highest concentrations in April and October and the lowest concentrations of all months in December (Fig. 15). This is confirmed when considering seasons. Here, the highest concentrations were found in Fall and the lowest in Winter (Fig. 16).

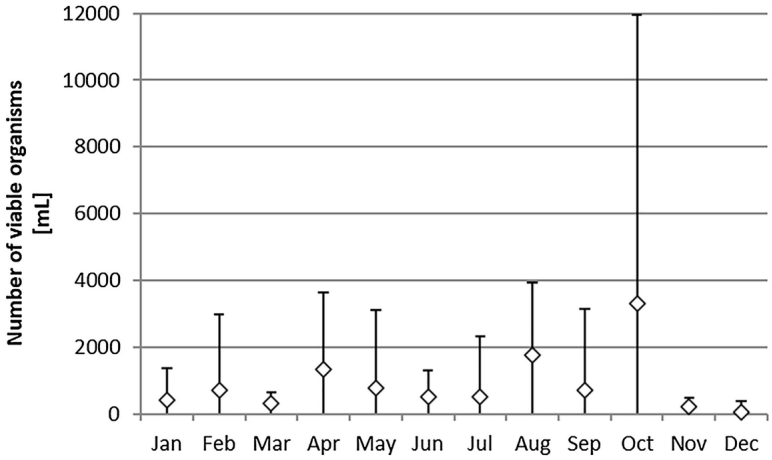

Fig. 15 Mean concentration of viable phytoplankton cells per mL of all sampling events per month

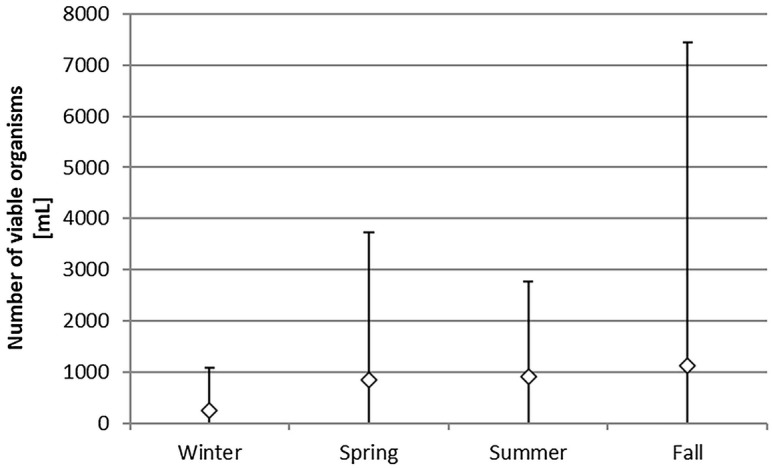

Fig. 16 Mean concentration of viable phytoplankton cells per mL of all sampling events per season

Figure 17 shows that the highest phytoplankton counts of viable cells above 4000 cells/mL were made in freshwater environments, with cell concentrations being almost 10 times higher compared to all other salinities. From oligohaline to hyperhaline conditions, the concentration ranges from ca. 400 to 650 viable cells/mL.

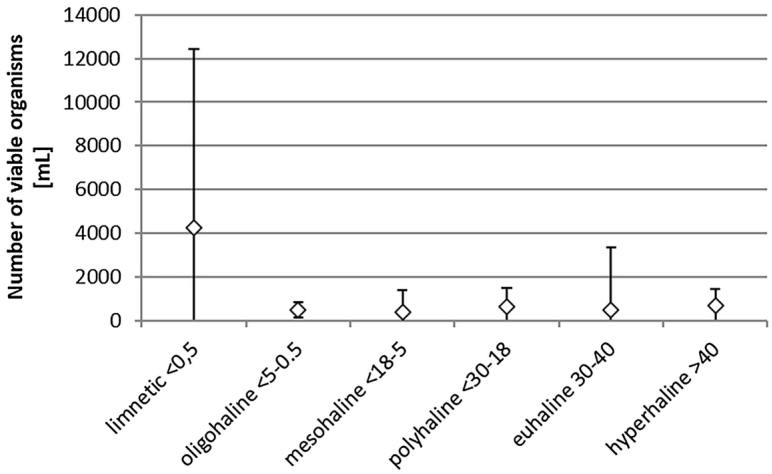

Fig. 17 Mean concentration of viable phytoplankton organisms per mL and water salinity of all sampling events. Salinity categories as in the Venice System (1959)

The highest concentration of viable phytoplankton organisms per mL was observed in samples between <15–10 °C and < 35–30 °C, and the lowest concentration was found in the highest water temperatures sampled (Fig. 18).

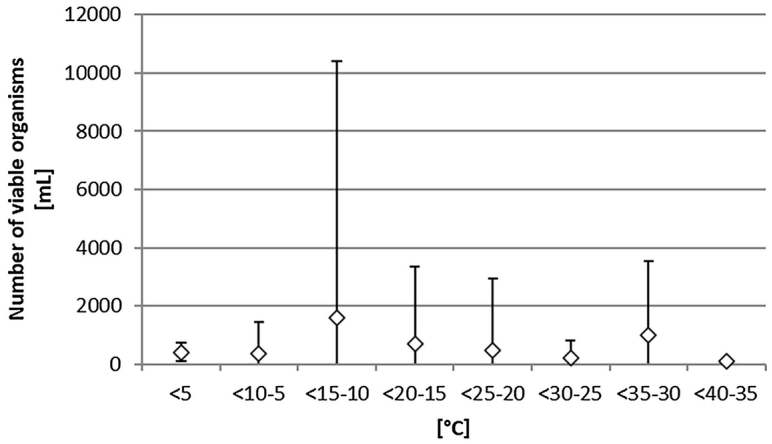

Fig. 18 Mean concentration of viable phytoplankton cells per mL and water temperature of all sampling events

Figure 19 documents that the highest concentration of viable phytoplankton cells per mL was found in the sampling events with a duration of 70–80 min. No clear trend was observed in which sampling event duration a lower or higher concentration of viable cells occurred.

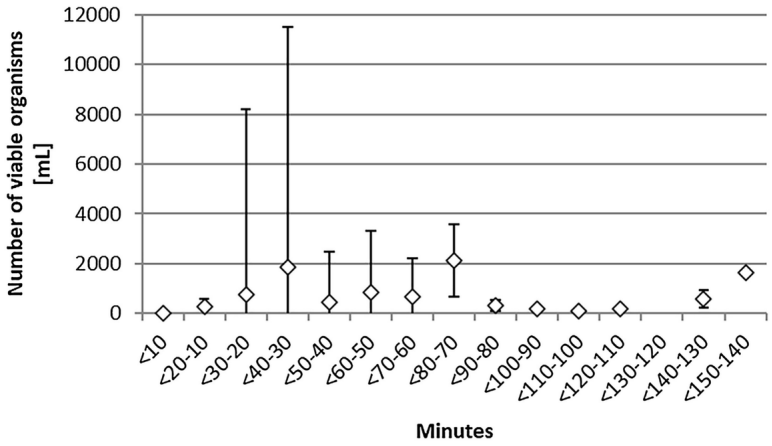

Fig. 19 Mean concentration of viable phytoplankton cells per mL according to the duration of all sampling events

High concentrations of viable phytoplankton cells per mL were observed during sampling events in waters below 1000 m depth. The highest concentration was found in water depths above 100–1000 m and in waters below 50 m deep (Fig. 20).

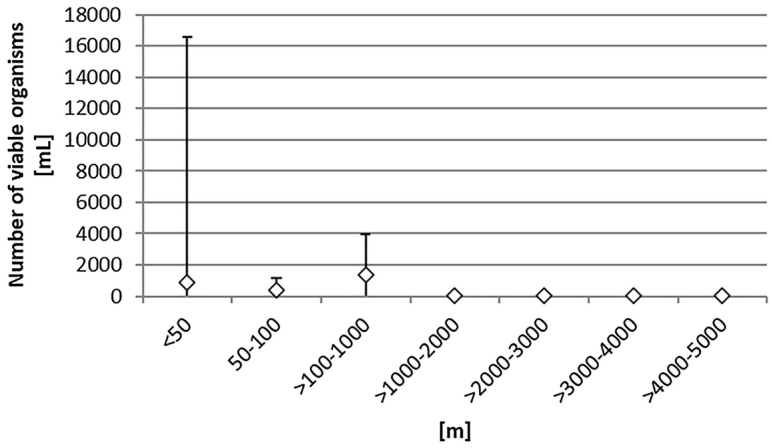

Fig. 20 Mean concentration of viable phytoplankton cells per mL according to mean water depth during all sampling events

In general, the closer the samples were taken to shore the higher was the mean concentration of viable phytoplankton. However, samples taken <150–125 NM from shore also showed high cell counts (Fig. 21). This was confirmed when comparing sampling events inside ports and during navigation, as samples taken in ports also had a much higher concentration of viable phytoplankton cells compared to sampling events during navigation (Table 5).

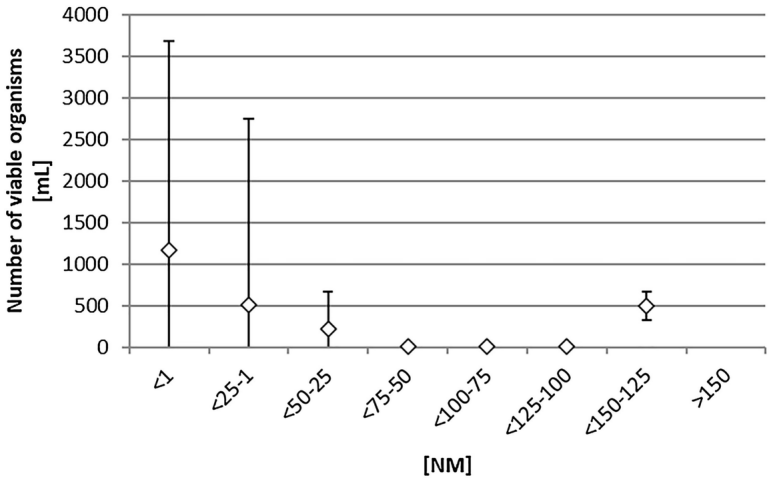

Fig. 21 Mean concentration of viable phytoplankton cells per mL according to mean distance from shore during the sampling event

Table 5 Concentration of viable phytoplankton organisms per mL according to the sampling event location inside a port or during navigation

	Sampling event location	
Organism	**In port**	**In navigation**
Mean	1222.0	322.5
Min	5.0	0.8
Max	20,924.0	6420.0

3.2.2 Zooplankton

In minimum 30 viable zooplankton individuals were found per m^3, the mean value was 4149.1 and the maximum value 32,115.7 viable ind./m^3 (Fig. 22).

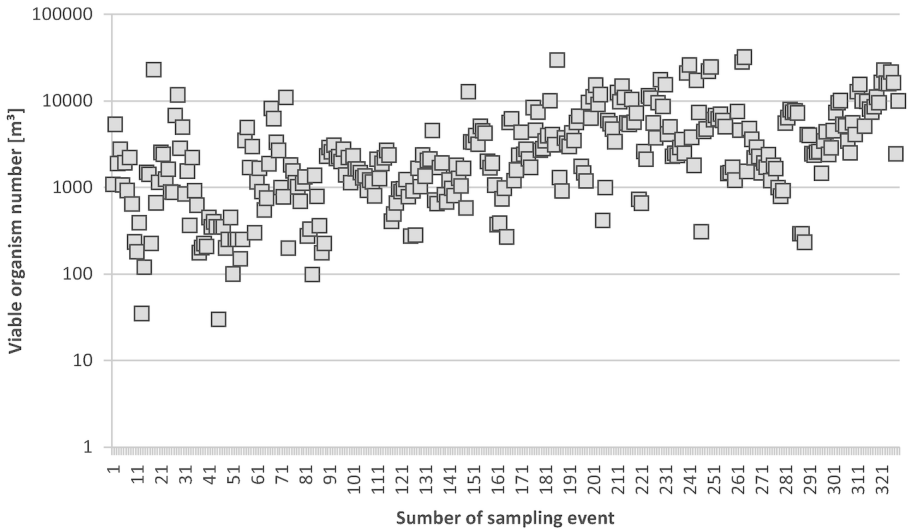

Fig. 22 Concentration of viable zooplankton individuals in all sampling events

The concentration of viable zooplankton per m^3 fluctuated over the months during which the sampling events were conducted. The highest counts were made in February, May, August and October and the lowest count of all months was observed in November (Fig. 23). In a seasonal analysis, the Spring and Summer sampling events result in almost identical high concentrations of viable zooplankton (Fig. 24).

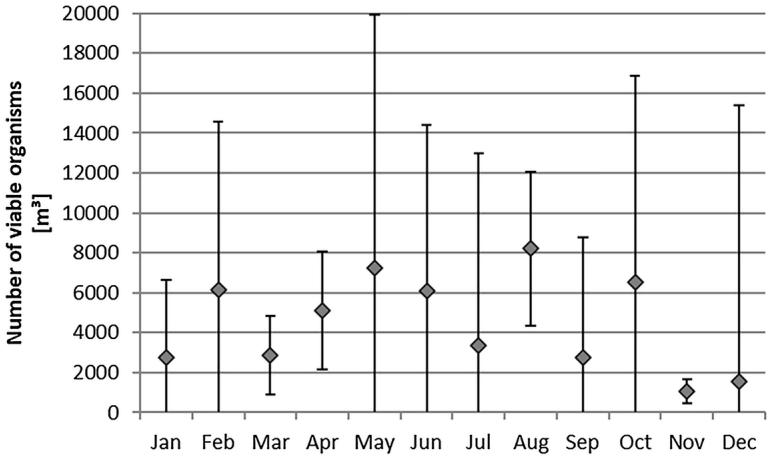

Fig. 23 Mean concentration of viable zooplankton per m^3 of all sampling events according to the month of sampling

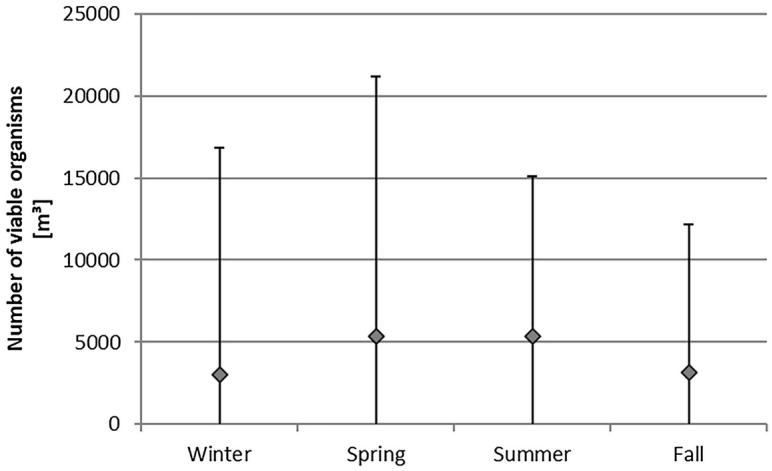

Fig. 24 Mean concentration of viable zooplankton per m^3 of all sampling events according to the season of sampling

The concentration of viable zooplankton per m^3 was highest in freshwater samples. With the exception of polyhaline water, the concentration shows a downwards trend from freshwater to hyperhaline conditions (Fig. 25).

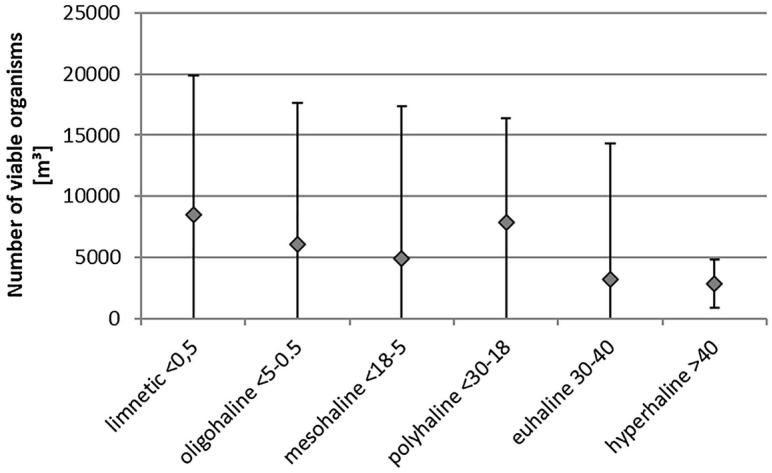

Fig. 25 Mean concentration of viable zooplankton organisms per m^3 and water salinity of all sampling events. Salinity categories as in the Venice System (1959)

The highest concentration of viable zooplankton per m^3 was found in samples with water temperatures of <35–30 °C, followed by the samples with <15–10 °C and below 5 °C (Fig. 26).

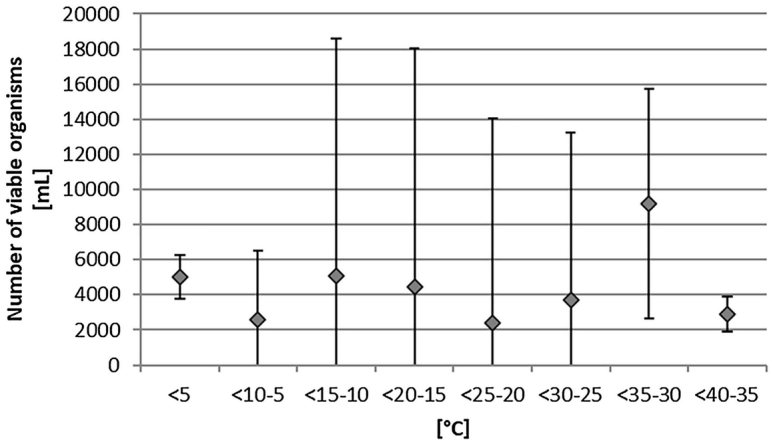

Fig. 26 Mean concentration of viable zooplankton organisms per m^3 sampled according to water temperature of all sampling events

The highest concentration of viable zooplankton organisms per m^3 was found in samples with volumes between 1500 and 1999 L. No strong fluctuation of the concentration of viable organisms occurred in sample volumes below 1500 L. In sample volumes above 2000 L, the concentration of viable organisms in a sample decreased by sample volume (Fig. 27).[1]

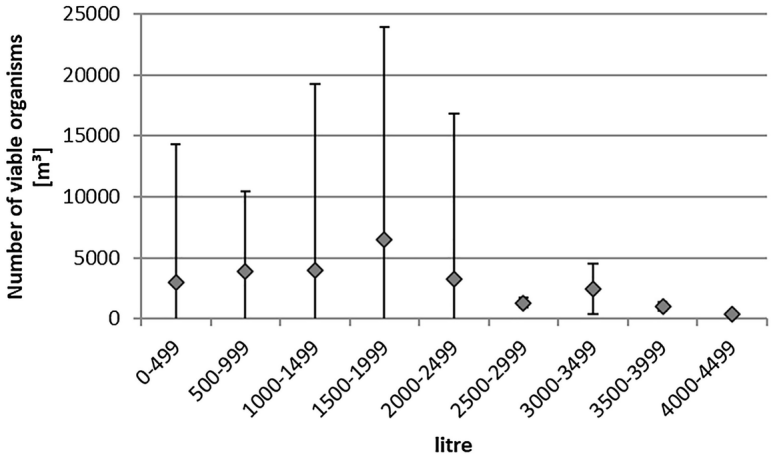

Fig. 27 Mean concentration of viable zooplankton organisms per m^3 sampled according to sample volume

Figure 28 documents that the highest concentration of viable zooplankton organisms per m^3 was found in the samples with a duration of 70–80 min. However, as for phytoplankton, also for zooplankton, no clear trend was observed in which sampling event duration a lower or higher concentration of viable organisms occurred.

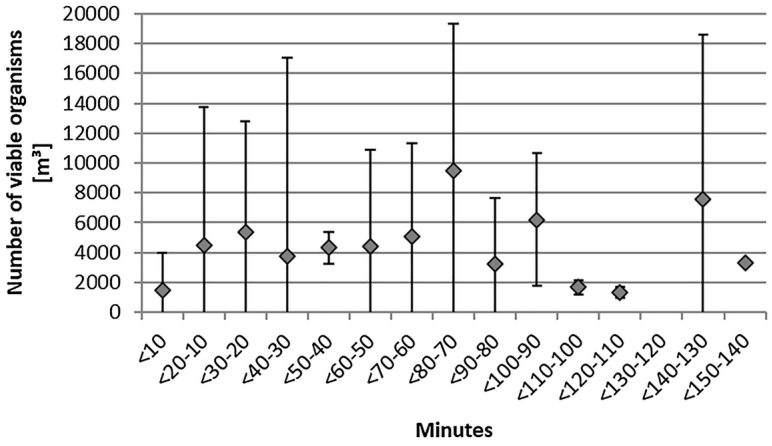

Fig. 28 Mean concentration of viable zooplankton organisms per m^3 according to the duration of all sampling events

The highest mean flow rate of all sampling events was 346 l/min, which occurred only once. When excluding this extremely high value, the mean flow rate during sampling varied from 9 to 97 l/min. The highest concentrations of viable zooplankton were observed in sampling events with mean flow rates of >20–30 and >70–80 l/min (Fig. 29).

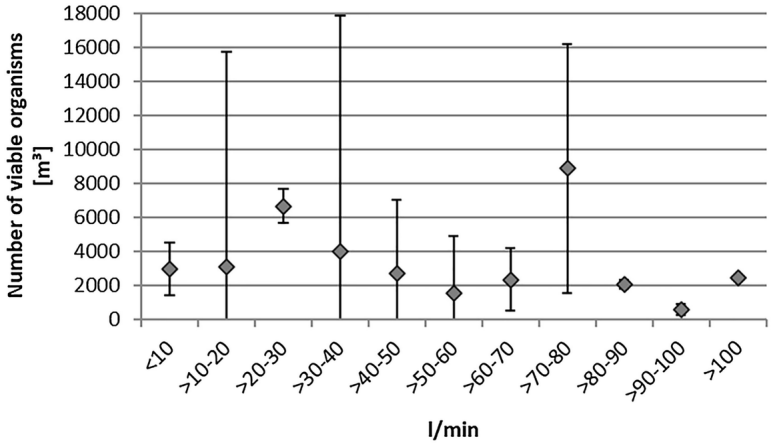

Fig. 29 Mean concentration of viable zooplankton organisms per m^3 according to the mean flow rate in l/min in all sampling events

The concentration of viable organisms was observed to change according to the water depth during the sampling event. The shallowest water depth at which a sampling event occurred was 4 m, and the highest was above 4700 m. In general, the shallower the water, the higher was the concentration of viable zooplankton individuals per m^3 in the samples. However, the second-highest concentration was found in the samples taken at above 3000 and below 4000 m water depth. It is interesting to note that during the eight sampling events in waters deeper than 4700 m, more than 600 viable ind./m^3 were observed (Fig. 30).

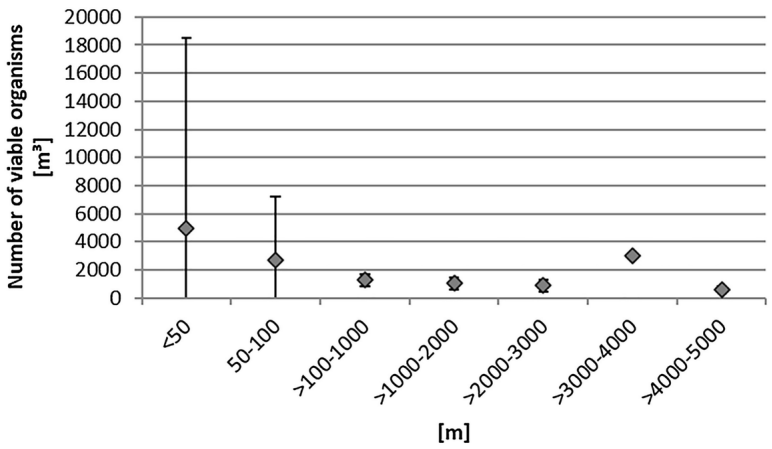

Fig. 30 Mean concentration of viable zooplankton organisms per m^3 according to mean water depth during all sampling events

The highest concentration of viable zooplankton per m^3 was observed in samples with a distance of less than 1 NM to the nearest land. Occasionally, organism concentrations were higher than 1000 per m^3 also in samples more than 100 NM offshore (Fig. 31), and samples taken in ports had a much higher concentration of viable zooplankton individuals compared to those sampling events, which took place during navigation (Table 6).

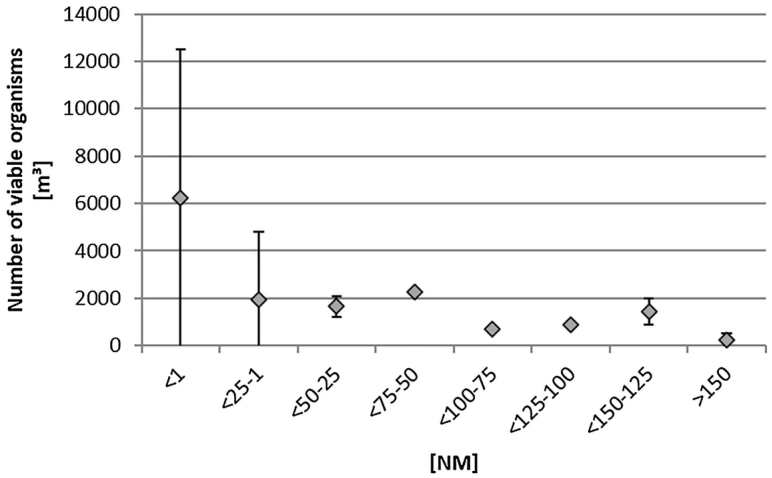

Fig. 31 Mean concentration of viable zooplankton organisms according to mean distance from shore during all sampling events

Table 6 Concentration of viable zooplankton organisms according to the sampling event location inside a port or during navigation

	Sampling event location	
Organism	**In port**	**In navigation**
Mean	6398.4	1669.0
Min	208.6	30.0
Max	32,115.7	11,757.1

According to BWMS test requirements, the concentration of viable zooplankton organisms per m^3 in the water was documented according to higher taxonomic groups for 299 sampling events, excluding certain pre-performance tests, where such data were not available. The most frequently found taxa were Arthropoda (all samples), Mollusca (68.9% of samples), Polychaeta (62.2%) and Rotatoria (33.4%). In 13 samples, fish eggs were

observed with moving embryos. Within the most frequently found group, i.e., Arthropoda, Copepoda, Cladocera and Cirrepedia prevailed. Larvae and adults were all grouped into the relevant higher taxon without splitting into different developmental stages (Table 7).

Table 7 Records of viable zooplankton individuals according to higher taxa in all sampling events

Taxon	Sub-taxon	Records in samples	
		Number	%
Arthropoda	Copepoda	299	100.0
	Cladocera	93	31.1
	Cirripedia	74	24.7
	Decapoda	30	10.0
	Amphipoda	17	5.7
	Mysidacea	12	4.0
	Isopoda	7	2.3
Mollusca		206	68.9
Polychaeta		186	62.2
Rotatoria		100	33.4
Turbellaria		24	8.0
Pisces (egg)		13	4.3
Nematoda		12	4.0
Chaetognatha		11	3.7
Cnidaria		10	3.3
Echinodermata		8	2.7
Bryozoa		8	2.7

The seasonality of the predominantly found taxa, i.e., Copepoda, Mollusca, Polychaeta, Rotatoria, Cladocera, Cirripedia and Decapoda, was analyzed. Copepoda, Mollusca, Polychaeta and Rotatoria were found every month. Cladocera were not found in December samples, Cirripedia not in November, Decapoda not in April and December. Most taxa were recorded in Spring to Fall samples, and winter samples showed the poorest diversity (Fig. 32).

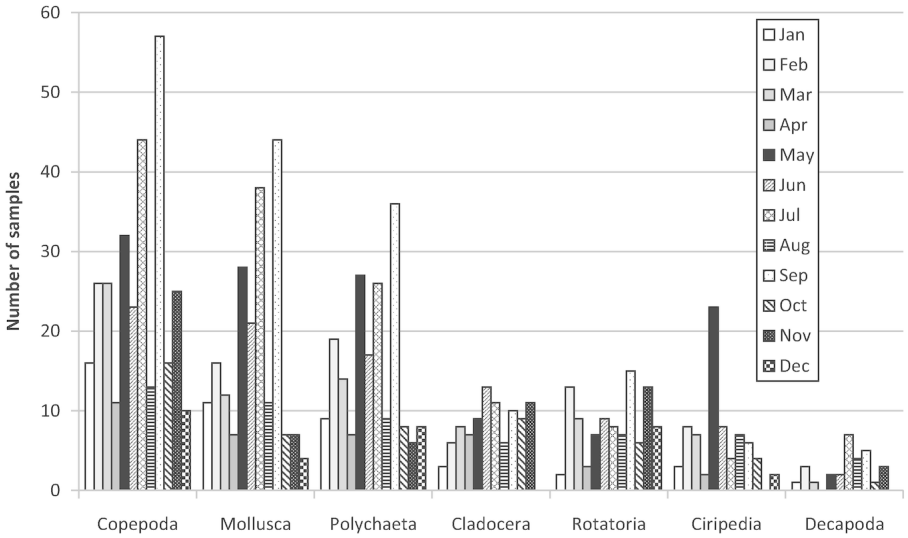

Fig. 32 Number of samples with the predominantly identified taxa per month in all sampling events

Copepoda, Mollusca, Polychaeta, Cladocera and Rotatoria were found in all salinities, whereas Cirrepedia and Decapoda predominantly occurred in samples of higher salinities (Fig. 33).

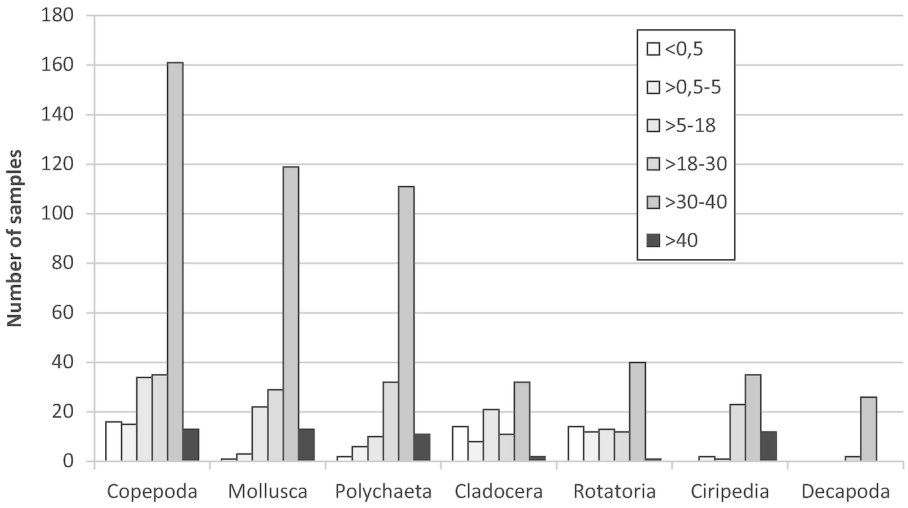

Fig. 33 Number of samples with the predominantly identified taxa per salinity (psu, <0.5 to >40) in all sampling events

Only in water depths below 100 m, all predominantly found taxa were observed. The greater the water depth was, the lower was the diversity of viable zooplankton taxa (Fig. 34) (as well as the abundance, as shown above in Fig. 30).

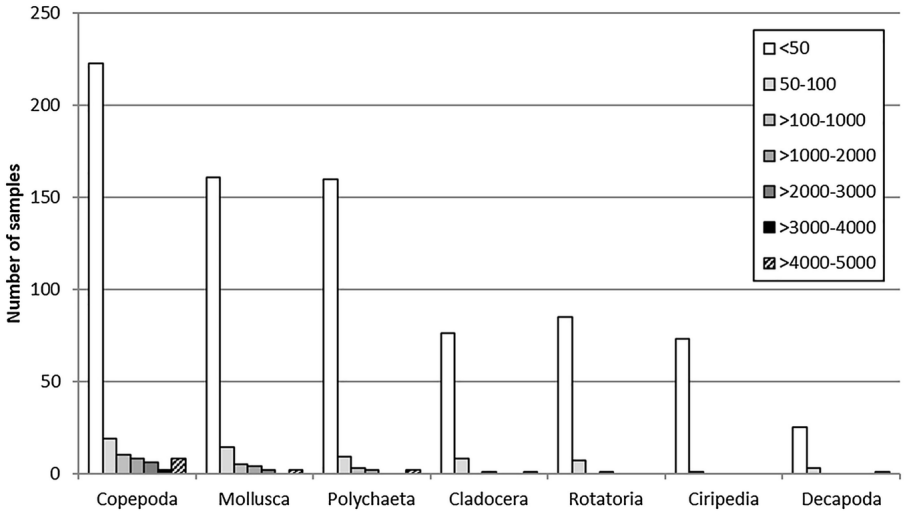

Fig. 34 Number of samples with the predominantly identified taxa per water depth (in meters, <50 to 5000) in all sampling events

Copepoda were the only taxon found in samples of all distances from shore. Mollusca and Polychaeta were frequently observed in samples closer to land than 50 NM. In samples taken more than 50 NM offshore, the diversity of viable zooplankton is considerably reduced (Fig. 35).

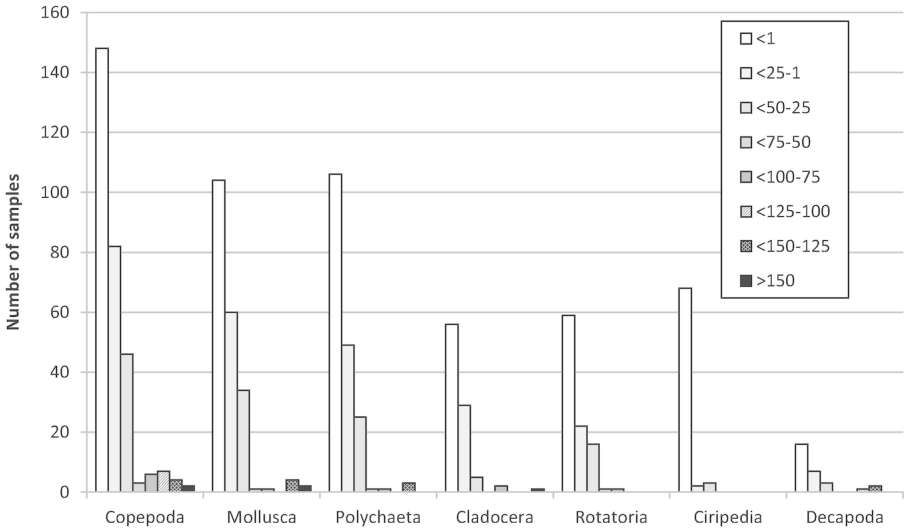

Fig. 35 Number of samples with the predominantly identified taxa per distance (in NM, <1 to >150) in all sampling events

Figure 36 shows that for all dominantly found taxa, their findings are more numerous inside ports compared to samples taken during navigation. This observation is strongest for Cirripedia, with 68 occurrences in samples from ports and only six observations during navigation sampling events.

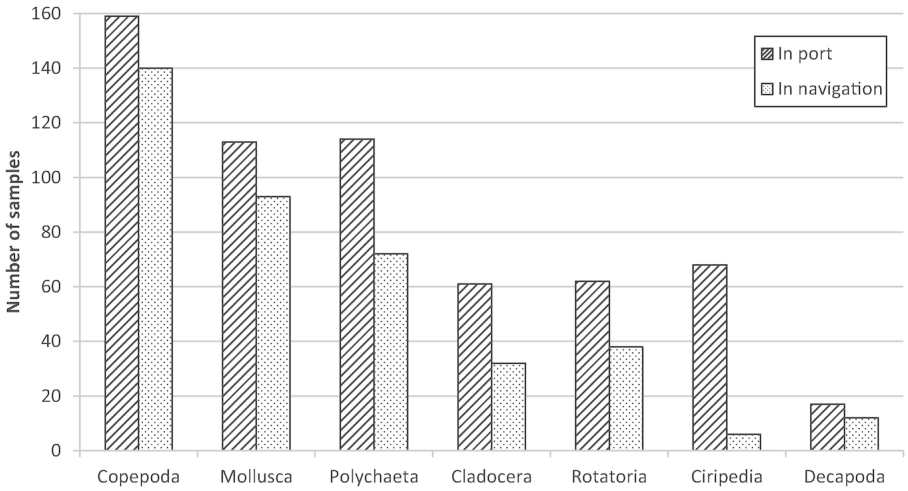

Fig. 36 Number of samples with the predominantly identified taxa in samples taken inside a port and during navigation

3.2.3 Interaction of Phytoplankton and Zooplankton

When comparing the phytoplankton and zooplankton concentrations of the identical sampling event with their mean concentrations over all sampling events, we noted that in ca. 9% of all sampling events, both organism groups were jointly above the mean concentration of all sampling events. In ca. 6.4% of all sampling events, we found that the phytoplankton concentration was above the mean concentration, but the zooplankton concentration in the same samples was below mean zooplankton concentration level. The reverse situation, i.e., when zooplankton was above mean concentration and phytoplankton below in the same sampling event, occurred in ca 17% of the sampling events (see Supplementary Table 1).

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4 Discussion

4.1 Sampling Points

We took all samples via in-line sampling points in the ballast water pipework of the vessels designed and installed to provide for isokinetic sampling. Such a sampling point was not available in the past but is nowadays needed to document the challenge water conditions in BWMS performance tests. In previous ballast water sampling studies, the samples were most frequently taken either via sounding pipes, tank hatches or openings, i.e., so-called manholes (Gollasch 1996; Olenin et al. 2000; David and Perkovic 2004; McCollin et al. 2007a; Briski et al. 2015). It has been documented that sounding pipe sampling results in different diversity and abundance compared to tank opening and in-line sampling results (Sutton et al. 1998; Gollasch et al. 2003). Studies using tank openings as sampling access point may deliver biased results, as light penetrates into the previously dark ballast tank during sampling, which may result in attracting organisms to migrate to the sampling point (Desai et al. 2018). Further, heterogeneity of organism distribution in ballast tanks was observed in several studies (Murphy et al. 2002; Taylor et al. 2007; Carney et al. 2013; Gollasch et al. 2003). For these reasons, it was noted that certain methods oversample and others undersample the organism concentration (Gollasch et al. 2003) and species diversity, and that the most representative approach to document ballast water biology is to take samples from in-line sampling points in the vessel's ballast water pipework (Gollasch and David 2017).

It should also be noted that most of the previous ballast water sampling studies were conducted on vessels after a voyage was completed so that the samples were taken before ballast water discharge. In contrast, we took the samples during ballast water uptake, i.e., before a vessel voyage. Therefore, comparing our in-line sampling results with findings from studies using other sampling points and having taken samples after vessel voyages is only possible on a limited scale (see phytoplankton and zooplankton chapters below).

4.2 Abiotic Factors

TSS difference for sampling events in ports and at sea were marginal, which likely reflects that most samples at sea were taken near the coast or in shallow seas, but not in mid-ocean. This may further indicate that some sampling events were conducted in ports with very low TSS content, as otherwise we would have expected a considerable difference of TSS samples taken inside ports and during navigation.

To evaluate to what extent the set TSS and POC values of (old and new) IMO test requirements as well as the ETV protocol requirements were achieved, we compared these requirements with our results (Table 8). These requirements were set for land-based BWMS tests with the aim to challenge BWMS with water conditions that reflect worst case conditions in ports. Our results show values above or below IMO and ETV required levels in different salinities. In marine water, all measured values were above IMO TSS requirement for BWMS land-based tests of the old and new G8 as well as the BWMS Code as >1 mg/L, but only a third of the measured values were also above ETV standard of >24 mg/L for this salinity. In brackish water conditions, measured values were rarely above IMO TSS requirements in BWMS land-based tests, whereas two-thirds of all the measured values were above ETV requirements. In freshwater, all the measured values were below IMO TSS requirements, and approximately one-third of the measured values were above ETV required.

Table 8 TSS and POC/POM requirements per salinity in the old and new G8 (IMO 2008b, 2016) as well as ETV Protocol (2010). How many times the requirements were reached is indicated in number and percentage

Guideline	Marine water					Brackish water					Freshwater		
	Value	# above	% above	# below	% below	Value	# above	% above	# below	% below	Value	# above	% ab
G8 old (2008)	>32 psu					3–32 psu					<3 psu		
POC	>1 mg/L	62	92,5	5	7,5	>5 mg/L	32	45,7	38	54,3	>5 mg/L	16	66,

Guideline	Marine water					Brackish water					Freshwater		
	Value	# above	% above	# below	% below	Value	# above	% above	# below	% below	Value	# above	% ab
TSS	>1 mg/L	73	100,0	0	0,0	>50 mg/L	6	8,3	66	91,7	>50 mg/L	0	0,0
G8 new (2016) and BWMS Code (2018)	28–36 psu					10–20 psu					<1 psu		
POC	>1 mg/L	62	73,8	22	26,2	>5 mg/L	4	66,7	2	33,3	>5 mg/L	16	72,
TSS	>1 mg/L	88	100,0	0	0,0	>50 mg/L	2	33,3	4	66,7	>50 mg/L	0	0,0
ETV (2010)	28–36 psu					10–20 psu					<1 psu		
POM	(>)4 mgL	48	57,1	36	42,9	(>)4 mg/L	4	66,7	2	33,3	(>)4 mg/L	16	72,
TSS	(>)24 mg/L	30	34,1	58	65,9	(>)24 mg/L	4	66,7	2	33,3	(>)24 mg/L	8	36,

For POC, the situation is more consistent. In freshwater and brackish water, approximately two-thirds of the measurements showed values above IMO and ETV requirements. In marine water, IMO POC requirements were reached by more than 90% of the sampling events as per the old G8 requirements (i.e., marine water = psu >32) and more than 70% as per the new G8/BWMS Code requirements (i.e., marine water = psu 28–36). ETV POC requirements were reached during slightly more than half of the sampling events.

In summary, TSS and POC measured values in marine water were well above IMO requirements, which means that the challenge water requirements are too low. However, TSS measured values in marine water were in many cases below ETV requirements, possibly indicating that these requirements might represent very challenging conditions. In brackish water, IMO POC and ETV Particulate Organic Matter (POM) requirements were reached by two-thirds of the sampling events, but TSS requirements to a lower extent. This possibly indicates that especially IMO TSS requirement of >50 mg/L for brackish water is set to a level which is very high. This is also the case for IMO TSS freshwater requirement, where none of our sampling events were above this IMO requirement as set in the old and new G8 as well as the BWMS Code.

Especially, TSS content in certain ports is much higher than what IMO and ETV require for the challenge water. One example is the freshwater, inner estuarine Port of Hamburg (Germany), where the long-term mean TSS content is above 50 mg/L, which matches well with IMO challenge water requirements, and this is already more than double of what is required by the ETV Protocol. However, the TSS content of the water between Hamburg and the North Sea, which is of brackish condition, frequently reaches concentrations above 300 mg/L with extremes even above 600 mg/L (Bergemann 2004). As a result, BWMS tests conducted in full compliance with IMO requirements may not mimic the situation vessels are exposed to in many ports, as the TSS content for BWMS tests is simply much lower than TSS content in many ports. This means that the challenge condition levels of TSS, especially in marine water, are set too low. First et al. (2014) also documented TSS values in marine waters of different regions, which in many occasions was well above IMO and ETV Protocol challenge water requirements.

First et al. (2014) also reported POM values in coastal waters, which were occasionally much higher than the challenge water requirements, but their values were lower than our findings. Cadee (1982) found an annual mean of 15.2 mg/L POC at one Dutch Wadden Sea sampling site, which is similar as in our samples. They reported that in a nearby site (<2 NM distance), POC values were mainly around 2 mg/L, with maximum values of 6 mg/L. This documents considerable seasonal and regional changes in POC levels even in a small area.

4.3 Phytoplankton

The concentration of viable phytoplankton cells in our study was in a similar range compared to the results of other ballast water sampling studies where samples were taken during or directly after ballast water uptake (Rigby and Hallegraeff 1994; Olenin et al. 2000; McCollin et al. 2007a; Okamoto et al. 2007; Simard et al. 2011; Briski et al. 2015; Wright et al. 2015).

In terms of water depth and distance from a shore, in general, higher concentrations of viable phytoplankton cells were observed during sampling events in nearshore waters shallower than 1000 m. Further, the closer to land the sampling event occurred, the higher was the concentration of viable cells. However, an elevated concentration of viable cells (ca. 500 cells/mL) was also found in samples taken more than 125 NM away from nearest land and this may indicate (the beginning of) an offshore algal bloom. The highest concentration of viable phytoplankton cells was >20,000 cells/mL and this was observed in Krefeld, an inland harbor in Germany.

The monthly phytoplankton concentration over all sampling events matched almost the phytoplankton seasonality in nature in temperate regions, where peak concentrations occur in spring and fall. Further, in winter, a very low concentration of viable cells is known and a summer depression was observed (Ott 1988). Earlier studies showed a similar phytoplankton seasonality when comparing results of 12 on board sampling events conducted by McCollin et al. (2007a).

The viable phytoplankton cell counts were also related to the water salinity and temperature. It was observed that the concentration of viable phytoplankton cells decreased with increasing salinity, i.e., less than half in concentration for marine waters compared to counts in freshwater sampling events. The highest concentration of viable phytoplankton cells was found in water temperatures between 10 and 15 °C.

The duration of the sampling event seems to have a limited impact on cell viability, as even in sampling times longer than two hours, high concentrations of viable cells were found.

IMO G8 Guidelines (IMO 2008b, 2016) and the ETV protocol (2010) require a certain concentration of viable phytoplankton cells in the challenge water during BWMS performance tests to make a test valid, i.e., >90 viable cells/mL. During 75 sampling events (ca. 20%), this requirement was not reached, which indicates how challenging it is to fulfill this requirement.

4.4 Zooplankton

The concentration of viable zooplankton organisms observed is in a similar range as documented in other ballast water studies considering ballast water uptake sampling (Lavoie et al. 1999; Gollasch et al. 2000; Olenin et al. 2000; McCollin et al. 2007b, 2008; Simard et al. 2011; Maranda et al. 2013; Briski et al. 2015).

High concentrations of viable zooplankton were always found in coastal samples with water depths below 50 m, which was also observed by Olenin et al. (2000). However, occasionally, zooplankton concentrations above 1000 ind./m^3 were observed in samples taken more than 100 NM offshore. All very high densities of viable zooplankton (>20,000 ind./m^3) were observed in samples taken inside ports. The highest concentration of zooplankton individuals with >32,000 ind./m^3 was also found in a port, i.e., in the freshwater Port of Hamburg, Germany.

The seasonality of the zooplankton concentration showed an April–June and August–October peak, which was also documented by McCollin et al. (2008) in their summary of 12 on board sampling events. Therefore, our results show a similar zooplankton seasonality as known from temperate waters (Ott 1988).

The volume of water sampled had an influence on the concentration of viable organisms, as we found low viable organisms' concentrations in sampling events when larger volumes were sampled. Larger sampling volumes may be a result of longer

sampling times and larger flow rates. We rarely found the concentration of viable zooplankton above the average concentration of all sampling events, i.e., in samples with a duration of 2 hours or more or in samples with flow rates >100 l/min. This may indicate that prolonged sampling and thereby filtration times with likely high pressure at the filter surface of the sampling net occur, and this is why we avoided filtering samples for phytoplankton.

According to IMO test guidelines (IMO 2008b, 2016, 2018) and the ETV protocol (2010), a certain concentration of viable zooplankton organisms needs to be in the challenge water for a valid test, and this was set as >90 ind./m^3. This requirement was not reached in only two cases, i.e., in Newcastle (UK) in December and in the Bay of Biscay in July. This means that in many ballast water uptake occasions, including also offshore areas, the organism concentrations are high enough to meet this requirement.

Regarding species diversity, we found Copepoda in all samples, no matter in which time of year, salinity, water depth, distance from shore and in samples taken inside ports as well as during navigation. Earlier studies have also documented that copepods are the dominating zooplankton taxon in ballast water samples (Gollasch 1996, Olenin et al. 2000, McCollin et al. 2007b). The next frequently found taxa were Mollusca and Polychaeta. They were also found in almost all samples, but not in waters deeper than 2000 m. In general, the diversity of viable zooplankton declined with increasing distance from shore and increasing salinity. It is interesting that Cirripedia were ten times more frequently observed in samples taken inside ports compared to offshore sampling events. This may be due to the hard substrate required to complete their life cycle, which is absent in offshore areas.

4.5 Phytoplankton and Zooplankton Interaction

Our monthly analysis showed that the Spring zooplankton peak occurred one month after the high phytoplankton concentrations, but other high viable zooplankton concentrations were also observed in February before the phytoplankton peak. As for phytoplankton, a zooplankton summer low was observed, but the lowest concentration occurred in November.

As for phytoplankton samples, the concentration of viable zooplankton individuals in freshwater was much higher compared to marine waters, and the concentrations of viable zooplankton increased with increasing water temperatures.

The concentration of viable phytoplankton and zooplankton in a sample seems to be related, as we documented in ca. 17% of all sampling events where zooplankton was above the mean concentration of all sampling events and phytoplankton in the same samples was below the mean. This may indicate the zooplankton grazing pressure on the phytoplankton. In ca. 6% of all sampling events, the reverse was found, and this may indicate the delayed zooplankton reproduction response to an increasing phytoplankton food supply. This situation is also found in nature. Especially in temperate regions, the phytoplankton and zooplankton show changes in their seasonal concentration with a phytoplankton bloom in Spring and Fall. Zooplankton follows this seasonality with some delay (Ott 1988; Joint et al. 2001; Umani et al. 2005; Peña et al. 2016).

4.6 Method Criticism

We pooled samples and analyzed results knowing that each sampling event is a one moment in time unique observation. McCollin et al. (2008) used a similar approach and published pooled sample results of a similar study, drawing conclusions based on a dozen samples. However, it is believed that our large number of >300 sampling events even more justifies this approach, as we conducted sampling events in all months, all seasons, in 22 different LMEs on all inhabited continents.

All samples were taken after the vessel’s ballast water pump, as there was no other way to extract water from the vessel’s pipework than on the pressure side of the ballast

water pump. Usually, vessels use impeller pumps for ballast water operations, and these pumps have an impact on the organisms in the water (Sassi et al. 2005). However, ballast pumps are relatively large and the pressure in the ballast piping after the pump is usually ~1.5–3 bars, which seems not too critical for most organisms, as our studies have shown when comparing the organism concentrations in a port with the organism concentrations after ballasting a ballast tank in the same port and at the same time when the port sample was taken. Peperzak (pers. comm.) also found in land-based tests of BWMS that the impeller pump used to generate the water flow had an impact on organism survival. However, this sampling point location after a pump is the only possible in-line sample access point prior BWMS. In consequence, the impact of such a pump occurred during all sampling events, and the pump effect was assumed to be similar and therefore not to substantially impair result comparison. However, noting the pump effect, the concentration of viable organisms in nature was likely higher, as documented in our samples.

As it was impossible to process the phytoplankton samples on board, we sent the samples to a land-based laboratory as soon as possible after the sampling event had ended. The sample storage and transport time may have been several days. However, our previous studies have shown that the storage conditions regarding temperature and light exposure have a stronger impact on algae survival as the storage duration. It was documented that a sample storage time less than two weeks in a dark and cool environment has little influence on the cell viability (Gollasch and David 2018). Therefore, the possible impact prior sample analysis due to storage and transport was kept to a minimum.

The modified zooplankton counting chamber with disconnected canals greatly improved the counting precision, as organisms could not freely swim between the canals as in the standard Bogorov chamber design. However, processing zooplankton samples at sea, and partly during heavy sea situations, remained a challenge.

4.7 Compliance of D-2 Without Management

In approximately 10% of the sampling events, the count of viable phytoplankton cells in the untreated water was lower than the D-2 standard, which indicates that in these cases, the IMO requirements for the smaller organisms would likely have been achieved without any ballast water management or treatment. This was observed in sampling events conducted in winter in northern Europe and in samples taken offshore in water depths higher than 1000 m. However, there is no guarantee that under these conditions the D-2 standard may be achieved without applying any ballast water management measure because it is also known that phytoplankton blooms occur offshore (e.g., Raine et al. 2001; Sha et al. 2015), and ballast water uptakes in such conditions would likely have resulted in concentrations of viable organisms above the D-2 standard.

The minimum concentration of viable zooplankton individuals in a sample was 30 ind./m^3 so that the concentration of the larger size organisms in nature was always above the D-2 standard. It is interesting to note that during the eight sampling events in waters deeper than 4000 m, more than 200 viable ind./m^3 were observed, with a maximum of 995 ind./m^3. This shows that ballast water exchange, even in open ocean, has sometimes limited effects in reducing the concentration of viable zooplankton organisms. Whether these open ocean organisms would be able to settle along the coast and survive wave actions, etc., is a different story.

5 Conclusions

The D-2 standard is unlikely achieved with unmanaged ballast water, and ballast water exchange would in most cases also not result in the same level of protection as the D-2

standard. However, in ca. 10% of our samples, the 10–50 µm organisms were already at uptake below the D-2 discharge standard.

For both phyto- and zooplankton, a much higher viable organism count was observed in freshwater, which makes BWMS tests here more challenging.

Low viable zooplankton organism concentrations were observed in sampling events when larger water volumes were sampled. These larger sampling volumes may be a result of longer sampling times and higher flow rates so that these parameters may have an influence on organism survival.

Failures of BWMS to meet the required ballast water discharge standards may indicate that the systems were not challenged enough during the testing phase or that they are not maintained and/or operated correctly (IMO 2015; Bakalar 2016; Campara et al. 2019; Soler-Figueroa et al. 2020; Gollasch & David, own observations).

Some land-based test requirements, such as IMO TSS in freshwater conditions, never occurred during our tests, and we documented that even higher values of other parameters than required in the challenge water may occur in nature. Therefore, we do recommend to increase the TSS requirements for the land-based tests to ensure that BWMS are sufficiently challenged so that they can handle the water conditions in ports also under the challenging conditions that occur in nature. A similar situation occurs for POC values, which also seem to be set as too low to represent challenging ballast water uptake conditions during type approval tests. We therefore conclude that BWMS need to be tested more rigorously to increase the likeliness that they achieve the D-2 standard under a greater variety of naturally occurring port water conditions to allow widespread compliance with ballast water management standards.

The biological challenge water conditions for shipboard BWMS tests were almost always reached in our shipboard tests for zooplankton, but in ca. 20% of the sampling events the phytoplankton requirement was not reached. Therefore, it seems that the challenge water standard for phytoplankton is stronger compared to the zooplankton requirement, and we recommend increasing the zooplankton limit to bring both biological challenge water standards to a similar strong level. IMO revised the G8 Guidelines and made them the BWMS Code without touching this aspect. However, IMO noted at the same time that more research results may provide evidence to re-negotiate certain aspects of this guideline/code and the BWM Convention. To generate knowledge, an experience building phase (EPB) was initiated by IMO to promote research in this field (IMO 2017a, b). The agreed EBP has three stages, i.e., data gathering (completed), data analysis (completed) and a review of BWM Convention and its supporting guidelines and guidance documents (to come). Key EBP findings are outlined in chapter “Compliance Monitoring and Enforcement of the Ballast Water Management Convention: The Port State Control Perspective”. We hope that our results will also be considered during EBP to justify certain changes in a future revision of the BWMS Code.

Acknowledgements

We express our grateful thanks to an endless number of helping hands at NIOZ, which were essential for processing the samples promptly. This refers especially to Marcel Veldhuis, Peter Paul Stehouwer (during their time at NIOZ) and Louis Peperzak (NIOZ). Their dedication made it possible to process the samples without delay, which was especially remarkable as some work was done during public holidays, including Christmas. Financial support was in part provided by the Interreg IVB-funded project Ballast Water Opportunity. For the support of the on board sample processing work, we also thank Dan Minchin, Sandra David, Jörg Heinrichs and Viola Liebich.

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Footnotes

1 Such an analysis was not performed for phytoplankton, as the sample volume was not fluctuating, but it was constantly 10 L.

© Springer Nature Switzerland AG 2024
M. David, S. Gollasch (eds.), *Global Maritime Transport and Ballast Water Management*, Invading Nature - Springer Series in Invasion Ecology 16
https://doi.org/10.1007/978-3-031-48193-2_4

Ballast Water Discharges and Safety Aspects of Using Active Substances for Ballast Water Treatment

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Abstract
This chapter gives an overview of the safety aspects of discharging ballast water into the environment due to the disinfection of the ballast water by the ship's ballast water management systems (BWMS) using active substances (AS). Such a system is required to undergo a testing process according to the International Maritime Organization (IMO) BWMS Code and Procedure (G9). The BWMS Code describes to which level the discharge of ballast water may contain harmful aquatic organisms and

pathogens (standard D-2), which is not dealt with in the current chapter. Procedure (G9) describes the procedure for approval of BWMS that make use of AS, which is the topic of this chapter. The consequences of the application of AS to the BWMS may be the formation of disinfection by-products (DBPs). Therefore, a technical working group has been established to ensure that the discharge of AS and DBPs remains below predefined acceptable limits to protect the environment, the crew and the ship against any side effects of the treatment by the BWMS. A risk assessment (RA) methodology has been developed by the Ballast Water Working Group of the UN Joint Group of Experts on the Scientific Aspects of Marine Environment Protection (GESAMP-BWWG). The methodology is based on internationally accepted RA procedures. The RA deals with the potential risks for the environment due to the direct discharge and for human health due to potential direct exposure of the crew of the ship or port State control officers when conducting their regular activities onboard, or due to the indirect exposure of the general public by swimming or by eating contaminated seafood. In case the treatment of the ballast water may cause a risk to the environment, the workers onboard, or the general public, such BWMS may not receive an approval recommendation by GESAMP-BWWG. The final decision about the acceptability of BWMS, and therefore, the allowance to market BWMS, is taken by the Marine Environmental Protection Committee of IMO based on the recommendation of GESAMP-BWWG. This chapter presents GESAMP-BWWG RA methodology with the theoretical background and the insights after >10 years of its application and improvements.

Keywords Ballast water management – Treatment – Disinfection by-products – Chemicals – Risk assessment – Environment – Human health

1 Introduction

Over the years, the Ballast Water Working Group of the UN Joint Group of Experts on the Scientific Aspect of Marine Environmental Protection (GESAMP-BWWG) has evaluated a wide variety of ballast water management systems (BWMS) using chemical (Active Substances (AS)), physico-chemical and physical technologies. The most common technique is in situ electrolysis, where seawater is used to produce chlorine and its oxidizing derivatives termed total residual oxidants (TRO). These processes are mostly combined with filtration or other means of separation and are normally followed by a neutralization step before discharge. Other treatment methods using ASs include ozonation, belonging to TRO-producing methods, and adding biocides or removal of organisms through flocculation.

To date, more than sixty BWMS that make use of ASs and/or Preparations have received Basic Approval (BA) from the International Maritime Organization (IMO) (BWM.2/Circ.34/Rev.10, Dec 2021), representing various technologies such as electrolysis, chemical addition (biocides) and ozonation. In addition, more than forty BWMS using ASs and/or Preparations have also received Final Approval (FA) (IMO 2020). There are also almost fifty BWMS without using AS, but these are not dealt with in this chapter. The main technique to treat ballast water using ASs is the electrochlorination/electrolysis method that produces the AS in situ on board of the ship. The reason is probably that suitable source water, which has to contain a certain amount of chloride, is abundantly available when sailing the world’s oceans.

Since a large part of BWMS that have been type-approved for use on vessels use ASs to treat ballast water, it can be expected that billions of tons of ballast water are

being treated with these substances and discharged all around the world. This gives a very high importance and challenges to the work of GESAMP-BWWG with regard to safeguarding human beings and the environment against potential harmful effects from such ballast water. The widespread use of ASs for treating ballast water has brought up new perspectives, challenges and issues, which are discussed in this chapter.

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2 Ballast Water Management Convention (BWM Convention)

Initially, ships subject to the Convention's ballast water management (BWM) requirements are required to exchange ballast water in open ocean. This is called the D-1 standard and is described in detail in Section D to the BWM Convention and is also indicated as the ballast water exchange standard. In due course, these ships are required to meet BWM performance standard that limits the number of viable organisms in discharged ballast water. After 2024, the D-1 standard will be phased out and completely replaced by the D-2 standard (IMO 2019). How ships should be able to confirm to the D-2 standard is described in detail in Guidelines (G8), as revised in 2018 (after entry into force called the Code for the Approval of Ballast Water Management Systems (IMO 2018)), but this is outside the purpose of this chapter.

BWMS that use ASs undergo evaluation process conducted by GESAMP-BWWG through a two-stage process, i.e., Basic Approval (BA) and Final Approval (FA). The IMO Procedure (G9) (IMO 2008) describes in detail how GESAMP-BWWG should evaluate BWMS. The reports of BWWG are subsequently sent to the Secretariat of IMO for decision-making at IMO's Marine Environment Protection Committee (MEPC).

3 The Type Approval Process

The aim of BWMS is to render aquatic species, including potentially harmful ones, non-viable. How this is achieved is a matter of choice for the developer of a BWMS and includes applying physical, biological or chemical methods. For physical and biological methods, only the Code (IMO 2018) has to be applied for testing of BWMS performance during the TA process, whilst for chemical systems the Procedure (G9) has been developed. The Code deals with the efficacy of the BWMS and the Procedure (G9) deals with the side effects of the AS, neutralizer and chemicals as disinfection by-products (DBPs) of the treatment process of BWMS. Side effects may occur for the environment, human health, including general public and workers (crew and port State control officers) and the ship itself, e.g., corrosion. As can be seen from the scheme, the approval process of a BWMS is a two-step approach, first is the BA and then secondly the FA (Fig. 1).

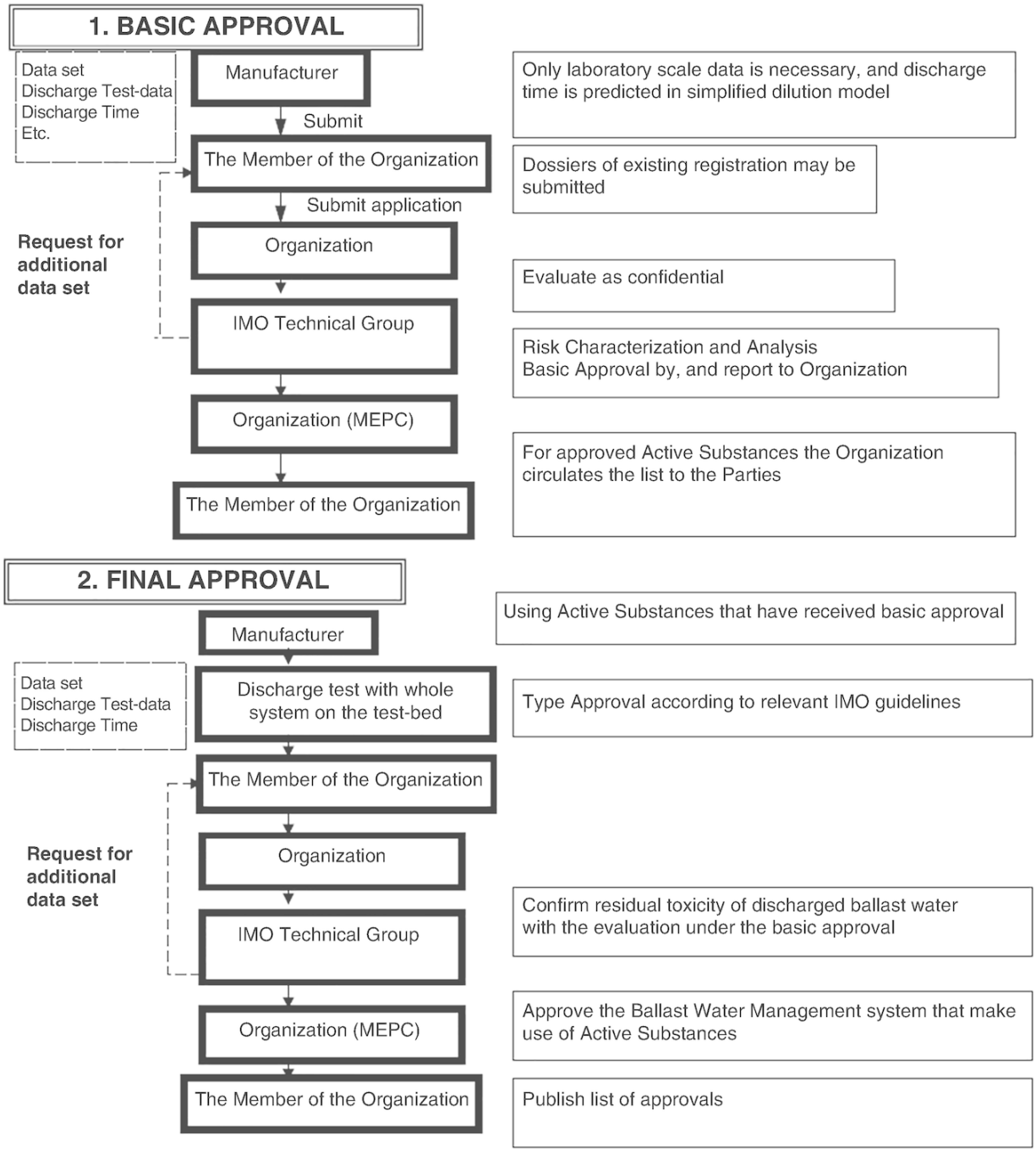
1. BASIC APPROVAL
Data set
Discharge Test-data
Discharge Time
Etc.
Manufacturer
Only laboratory scale data is necessary, and discharge time is predicted in simplified dilution model
Submit
The Member of the Organization
Dossiers of existing registration may be submitted
Submit application
Request for additional data set
Organization
Evaluate as confidential
IMO Technical Group
Risk Characterization and Analysis
Basic Approval by, and report to Organization
Organization (MEPC)
For approved Active Substances the Organization circulates the list to the Parties
The Member of the Organization
2. FINAL APPROVAL
Using Active Substances that have received basic approval
Manufacturer
Data set
Discharge Test-data
Discharge Time
Discharge test with whole system on the test-bed
Type Approval according to relevant IMO guidelines
The Member of the Organization
Request for additional data set
Organization
Confirm residual toxicity of discharged ballast water with the evaluation under the basic approval
IMO Technical Group
Approve the Ballast Water Management system that make use of Active Substances
Organization (MEPC)
Publish list of approvals
The Member of the Organization

Fig. 1 Scheme showing BA and FA process of a BWMS making use of ASs (IMO 2008) [Materials are reproduced with the permission of the International Maritime Organization (IMO), which does not accept responsibility for the correctness of the material as reproduced: in case of doubt, IMO's authentic text shall prevail. Readers should check with their national maritime Administration for any further amendments or latest advice. International Maritime Organization, 4 Albert Embankment, London, SE1 7SR, United Kingdom]

The use of the term TA is somewhat ambiguous. Sometimes with TA, the whole process of evaluation from BA and FA until marketing allowance of BWMS is meant, but it relates only to the process after the Final Approval has been granted and refers to the fully developed BWMS. This unclarity may be caused by the fact that non-chemical systems may apply directly for TA, but chemical systems have to achieve BA and then FA. Regularly land-based testing of BWMS is used to ascertain biological performance for TA and at the same time obtain samples for chemical analyses for the FA.

Based on the Procedure (G9), GESAMP-BWWG has developed over the years a methodology according to which a BWMS using an AS has to be evaluated for potential side effects. The methodology describes in detail the data requirements for BA and for FA as well as the risk assessment (RA) calculation procedures to be followed. The newest version of the Methodology (Rev.5) was adopted by IMO in 2022 (IMO 2022a). The data requirements are the identification of AS, the physico-chemical characteristics, the ecotoxicological data and the toxicological data. Recommendations are based on the so-called risk quotients, defined by an appropriate exposure estimation and an appropriate no-effect estimation; for the environment, these are the ratios of the Predicted Environmental Concentration (PEC) to the Predicted No-Effect Concentration (PNEC) (PEC/PNEC ratios) and for human health, the risk characterization ratios (RCRs).

The data requirements for BA and FA are different. The main difference is related to the requested ecotoxicological effect data, which for the FA are to be carried out with the treated effluent of the full-scale BWMS. In the BA set-up, it is considered sufficient to develop a laboratory version of BWMS, and in FA set-up, a fully developed BWMS with at least a capacity of 200–250 m^3/h has to be used. This

requires a relatively large test site installation to carry out this type of test. Therefore, specialized test facilities were built in several areas of the world, meeting also different climatological areas. The test facilities organized themselves in a worldwide cooperative body called Global TestNet.[1] The members of Global TestNet generally perform the tests needed to achieve BA and/or FA through the evaluation of the test results by GESAMP-BWWG.

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4 The Role of GESAMP-BWWG and the Methodology

GESAMP-BWWG was set up by GESAMP in 2006 in response to the request by IMO to assist the BWM Convention implementation by assessing the risks of BWMS to the marine environment, human health, including the ships' crew, and to the safety of the ship. GESAMP-BWWG comprises of a multidisciplinary team of experts in the fields of chemical RA, ecotoxicology, occupational hygiene and toxicology, as well as ship construction and engineering.

The experts working for GESAMP-BWWG act independently in their individual capacity and are bound by a Statement of Acceptance that ensures that proprietary data is treated as confidential. Please note that all authors of this chapter are presently, including chairperson and vice-chairperson, or have in the past been members of GESAMP-BWWG. GESAMP-BWWG only evaluates the safety aspects of BWMS, while it is not responsible for assessing the biological efficacy in treating ballast water regarding Regulation D-2 of BWM Convention.

On behalf of the manufacturer, national Administrations (Governments) submit applications regarding a given BWMS to MEPC at IMO. The submissions contain a non-confidential and a confidential part. The non-confidential

part is available for all Administrations attending MEPC, while the confidential part, which may contain confidential business information, is only submitted to IMO and made available for the experts in GESAMP-BWWG. These submissions once accepted for evaluation are processed by IMO on a first-come, first-served, fee-paying basis and sent to GESAMP-BWWG for assessment. The submissions are first checked for completeness and their content summarized in a standard format by an IMO consultant and then evaluated by GESAMP-BWWG, firstly for BA according to IMO's "Procedure for approval of ballast water management systems that make use of ASs" (G9) and following the GESAMP-BWWG Methodology, as published by IMO. As part of BA, GESAMP-BWWG makes a series of recommendations that the manufacturer is advised to address prior to re-submitting a dossier as a second step for FA, which is then handled in a similar manner.

GESAMP-BWWG, through MEPC, may make additional recommendations to the Administration in question with a bearing on the TA. Once approval through the first two steps has been achieved for a given BWMS, the submitting Administration is then responsible for issuing a TA for commercial scales and installations on board ships.

The reports containing the findings and recommendations of GESAMP-BWWG are peer-reviewed by its parent body GESAMP, and once approved, the recommendations are communicated to IMO for consideration by MEPC. Once endorsed by MEPC, TA process may be completed by the relevant Administration.

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5 Active Substances Used and the Issue Concerning Discharge of Ballast Water

5.1 Active Substances (AS) and Relevant Chemicals (RC)

Ballast water can be chemically treated by the use of ASs, which are defined as “a substance or organism, including a virus or a fungus, that has a general or specific action on or against Harmful Aquatic Organisms and Pathogens” (IMO 2004). They can be stored in the form of preparations or generated on board. Many ASs are associated with so-called relevant chemicals, i.e., “transformation or reaction products that are produced during and after employment of the BWMS in the ballast water or in the receiving environment and that may be of concern to the ship’s safety, aquatic environment and/or human health” (IMO 2017).

The most commonly used ASs are strong oxidants such as hypochlorite, ozone or peracetic acid. Hypochlorite (or hypochlorous acid) is often generated on board by applying an electrolytic cell to seawater of sufficient salinity (Eqs. 1 and 2). Sometimes, it is also released from preparations containing sodium hypochlorite (Eq. 3) or dichloroisocyanurate (Eq. 4):

$$2Cl^- + 2H_2O \rightarrow Cl_2 + H_2 + 2OH^- \tag{1}$$

$$Cl_2 + H_2O \rightleftharpoons HCl + HOCl \tag{2}$$

$$NaOCl + H_2O \rightarrow NaOH + HOCl \tag{3}$$

$$C_3N_3O_3Cl_2Na + 2H_2O \rightarrow C_3N_3O_3H_2Na + 2HOCl \tag{4}$$

When ozone is used to treat the ballast water, it is always produced in situ from the molecular oxygen contained in ambient air:

$$3O_2 \rightarrow 2O_3 \tag{5}$$

Peracetic acid is used by some BWMS, and it is available as a commercial preparation, in which it is stabilized as an

equilibrium mixture with hydrogen peroxide:

$$CH_3COOH + H_2O_2 \rightleftharpoons CH_3C(O)OOH + H_2O \quad (6)$$

All mentioned oxidants react rapidly with bromide (Br^-) to give hypobromous acid (HOBr) or hypobromite (BrO^-):

$$HOCl + Br^- \rightarrow Cl^- + HOBr \quad (7)$$

$$O_3 + Br^- \rightarrow O_2 + BrO^- \quad (8)$$

$$CH_3C(O)OOH + Br^- \rightarrow CH_3COO^- + HOBr \quad (9)$$

If seawater which has a naturally high concentration of bromide is treated with AS, hypobromous acid or hypobromite becomes the major oxidant species, while other halogen-containing oxidants are formed in smaller quantities. For reasons of practicality, all oxidant species are quantified under the sum parameter TRO, which GESAMP-BWWG then considers as AS in the evaluation of such BWMSs.

Not many different ASs are used by BWMS and most are originating from the technology of treating drinking water, which is directly applicable for the disinfection of ballast water. Table 1 gives an overview of ASs applied so far.

Table 1 Overview of AS used in BWMS, with their MADC (modified after David et al. 2018)

Active substance	**Number of BWMS**	**MADC (mg L^{-1})**
Chlorine dioxide	2	0.1[a]
Hydrogen oxide radical	4	Not applicable[b]
Hydrogen peroxide	2	0.5
Hydrogen peroxide/peracetic acid	3	0.5/0.3
Hypochlorous acid	27	0.1
Ozone	6	0.1

Active substance	Number of BWMS	MADC (mg L^{-1})
Polyaluminium chloride/polyamide sodium acrylate	1	Not defined[c]
Sodium dichloroisocyanurate (NaDCC)	2	0.1

[a]Values of 0.1 are TRO-values expressed as Cl_2

[b]$OH^{\bullet}$ has only a lifetime of milliseconds

[c]This is more a physical than a chemical process

The environmental acceptability of an AS is described by its Maximum Acceptable Discharge Concentration (MADC), which is established by GESAMP-BWWG during its evaluation process. MADC takes into account the potential effects on aquatic ecosystems based on known ecotoxicity testing with ASs. Because the basic set of ecotoxicity testing for the ASs is generally too limited, GESAMP-BWWG also founded MADC on its expert judgement and the expertise achieved with the drinking water applications. The dose of ASs is, however, much higher than in drinking water systems or even other applications, like preventing biofouling in cooling towers, where the dose is limited to up to 0.5 mg TRO L^{-1}.

Many systems apply electrochlorination to generate the AS chlorine (Cl_2), as hypochlorous acid (HOCl) or hypochlorite (OCl^-), or another form that may be converted to TRO. TRO is then generally expressed as Cl_2. In BWMS, dosages up to 20 mg TRO L^{-1} are proposed in the application dossiers, although most systems apply a dose less than 10 mg TRO L^{-1}. The reason for this limitation is that in the experience of the GESAMP-BWWG, corrosion of equipment and piping generally does not occur below a TRO concentration of 10 mg L^{-1} expressed as Cl_2, and that applicants try to avoid conducting the comprehensive and lengthy corrosion tests.

5.2 Neutralization

ASs cannot be discharged in concentrations higher than MADC. Therefore, after having performed its disinfecting action, the remaining concentration, if still above MADC, should be neutralized before discharge. The neutralization is performed with substances that reduce the oxidative potential of TRO. Substances mostly used as neutralizers are sodium thiosulfate or sodium sulfite.

The reaction equations for these substances are as follows:

for sodium thiosulfate:

$$Na_2S_2O_3 + 4OCl^- + H_2O \rightarrow 2NaCl + 2SO_4^{2-} + 2HCl \quad (10)$$

for sodium sulfite:

$$Na_2SO_3 + Cl_2 + H_2O \rightarrow Na_2SO_4 + 2HCl \quad (11)$$

5.3 Formation of Disinfection By-Products (DBPs)

Chemical oxidants interact in a variety of ways with the organic matter, including organisms, present in the ballast water. As a result of these reactions, large organic molecules are broken down and organisms are destroyed or inactivated. In side reactions, DBPs are formed. DBPs are small molecules that often contain halogen atoms, such as trihalomethanes, halogenated acetic acids, halogenated acetonitriles or halogenated phenols, but also non-halogenated aldehydes or ketones may be formed. Inorganic bromate (BrO_3^-) is frequently considered a DBP, as well. Table 2 shows the ten most frequently found DBPs and their maximum concentrations measured during land-based testing of BWMS (David et al. 2018).

Table 2 Most frequently identified DBPs during land-based testing of BWMS (modified after David et al. 2018)

DBP	Frequency	Maximum discharge concentration ($\mu g\ L^{-1}$)
Bromochloroacetic acid	27	246.7
Dibromoacetic acid	34	230.0
Dibromochloromethane	33	120.0
Dichloroacetic acid	21	77.5
Dichlorobromomethane	27	70.5
Monobromoacetic acid	30	191.0
Monochloroacetic acid	21	495.0
Tribromoacetic acid	26	970.0
Tribromomethane	36	890.0
Trichloromethane	21	257.0

It should be noted that a number of variables influence the exact outcome of DBPs formation (Shah et al. 2015). These are mainly the type and concentration of the oxidant, the reaction time and several quality parameters of the treated water, such as salinity, pH, temperature and the concentration and molecular characteristics of dissolved organic matter. Generally, in seawater, brominated DBPs will predominate for all mentioned oxidants, because all their reaction pathways involve hypobromite as major secondary oxidant. However, in freshwater, the outcome is more diverse: while hypochlorite will mainly produce chlorinated DBPs, ozone and peracetic acid lead to less DBPs formation. DBPs formation increases over time in the presence of residual unreacted oxidants. Measurements during land-based testing are taking up to 5 days.

Many BWMS are designed to use a substantial excess of AS to prevent regrowth in the ballast tanks. In the case of long journeys, DBPs formation may therefore be higher than during testing. On the other hand, DBPs formed also start to degrade, e.g., through hydrolysis. The overall outcome cannot easily be predicted. A particularly strong

influence on DBP formation is associated with the type and quantity of organic material present that can react with the oxidants.

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6 Discharge of Ballast Water: Risk Assessment for the Environment and Human Health

At the discharge of ballast water to the environment of the harbour or even at sea, DBPs will enter the aquatic ecosystem and thereafter will distribute further, and depending on its physico-chemical and (eco-)toxicological properties, the substances may have effects on the aquatic organisms and also on humans. Therefore, the GESAMP-BWWG carries out a RA for all main substances in the discharge: the AS and DBPs that are determined in concentrations higher than the detection limit of the specific substance.

The RA generally is carried out according to the scheme in Fig. 2. The scheme is equally valid for risks to the environment and risks to humans. The applicant of a BWMS submits a dossier with all relevant information, described in Procedure (G9) to IMO. In the dossier, datasets, physico-chemical characteristics and effect information on aquatic organisms and humans are included. These data are used to estimate the potential hazards for aquatic organisms or humans according to the right-hand side of the scheme depicted in Fig. 2.

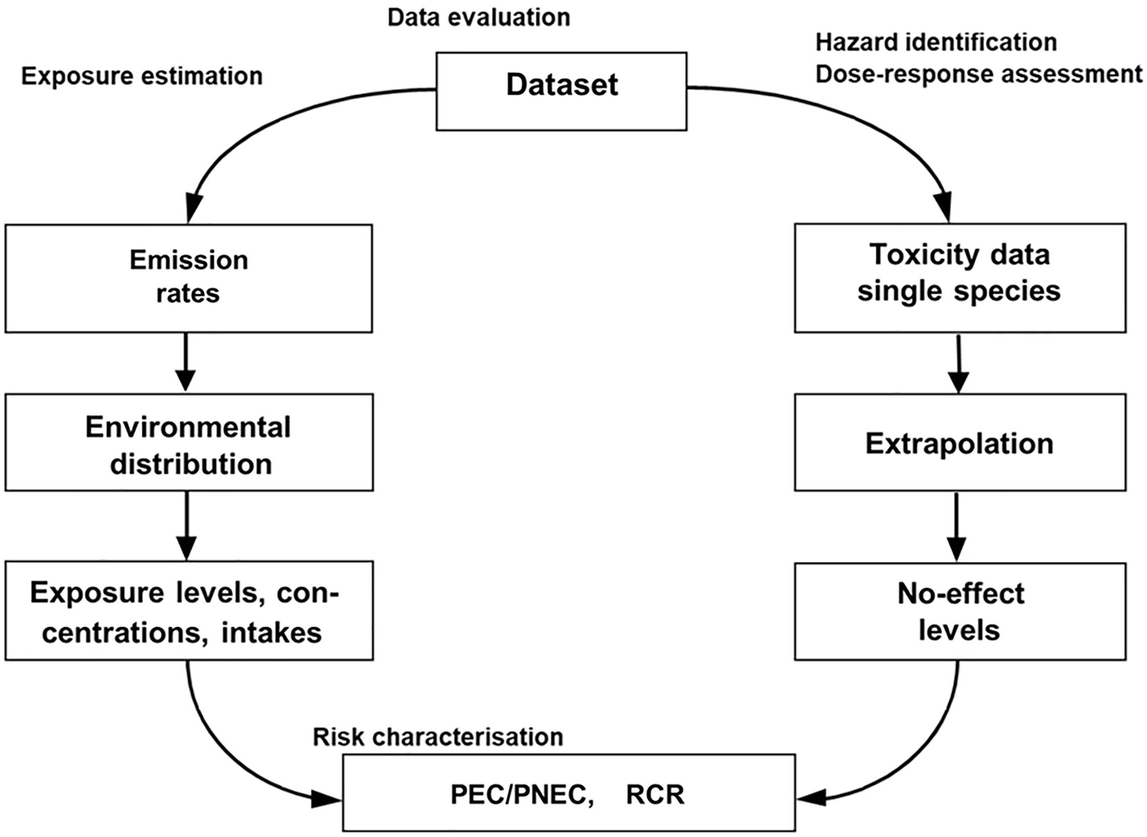

Fig. 2 The general RA process of chemicals

Generally, toxicity tests are performed with only one species, like rats in case of human toxicology or fish in case of aquatic organisms. Based on these single-species toxicity tests, an extrapolation is performed to a PNEC or a derived no-effect level (DNEL) for humans. Some substances may have carcinogenic or mutagenic characteristics; for these substances, instead of a DNEL, a DMEL (derived minimal effect level) is determined, which is subsequently used in the RA.

On the left-hand side of Fig. 2, the exposure to the substances is analysed. If there is no exposure to a substance, there is obviously also no risk. The exposure is determined mainly by the dose used for the disinfection, the emission, as well as by the physico-chemical characteristics of the substance, e.g., its volatility, its solubility, its degradation potential, etc. The substance may be distributed mainly to the water phase, to the air or to

the sediment. Based on mass balance considerations, an estimation is made to which concentrations the discharge of the substances may lead. Note that the discharge concentrations for ballast water are measured concentrations. Taking care that the exposure concentrations or levels and the effect concentrations or levels are in the same units, they can be easily compared by calculating the ratio of the two estimations. This leads to a risk characterization quotient defined by:

$$\text{for the environment :} \quad \mathrm{RCR_e} = \mathrm{PEC/PNEC} \tag{12}$$

$$\text{and for human health :} \quad \mathrm{RCR_h} = \mathrm{PEL/DNEL \text{ or } RCR_h = PEL/DMEL} \tag{13}$$

in which:

$\mathrm{RCR_e}$ = risk characterization ratio for the environment
PEC = predicted environmental concentration
PNEC = predicted no-effect concentration
$\mathrm{RCR_h}$ = risk characterization ratio for human health
PEL = predicted exposure level (or concentration)
DNEL = derived no-effect level (or concentration)
DMEL = derived minimal effect level (or concentration)

If $\mathrm{RCR_e}$ or $\mathrm{RCR_h}$ is greater than 1, the conclusion is that a potential risk cannot be excluded, and additional information may be required, while in the case that $\mathrm{RCR_e}$ or $\mathrm{RCR_h}$ is less than 1, a potential risk should be considered as acceptable, i.e., no unacceptable risk will result from exposure, and the use of BWMS should be regarded as safe for the environment or human health.

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7 Environment

7.1 Predicted Environmental Concentration

PEC for the relevant chemicals in RA after discharge is determined using the Marine Anti-fouling Model for

Predicting Environmental Concentrations (MAMPEC BW 3.1.0.3 model), developed by Van Hattum et al. (2016). The original MAMPEC model was adjusted after discussions with GESAMP-BWWG to make it fit for the purpose of the application of BWMS. A detailed description of the model is presented in the Methodology of GESAMP-BWWG (IMO 2017). In practice, the model has been incorporated in the Global Integrated Shipping Information System (GISIS), accessible via IMO (password protected) or it may be downloaded from the website of Deltares (www.deltares.nl).

Each substance is characterized with its physico-chemical properties, like molecular weight, solubility, vapour pressure, Henry's Law constant, etc. There is also a possibility to indicate certain degradation properties like hydrolysis, photolysis and biodegradation, but these features are not used in the first Tier calculations, if needed they may be used for higher Tier estimations. The emission to the harbour is based on the concentration of the substances in the neutralized discharged ballast water as presented in the data dossier at submission of BWMS to IMO. The default assumption is that an amount of 100,000 m^3/d of ballast water is discharged into the harbour. The model does not include features like different types of BWMS together discharging to the harbour. The output of the model are PECs as a yearly averaged concentration with a maximum, an average, a median and a minimum estimation in the harbour as well as in the surrounding waters outside the harbour. In principle, GESAMP-BWWG uses the maximum measured concentrations as the basis for the RA.

To account for local ballast water discharge effects, the concentration near ship is estimated using the formulae suggested in Zipperle et al. (2011):

$$C_{\max} = \frac{C_{\mathrm{BW}} + (S-1) \cdot C_{\mathrm{mean}}}{S} \tag{14}$$

where:

$C_{\max}$ = the maximum concentration due to near ship exposure (µg L^{-1}) = $PEC_{nearship}$
C_{BW} = the concentration measured in the discharged ballast water (µg L^{-1})
S = dilution factor based on sensitivity analysis with a higher Tier model, default value = 5
C_{mean} = the mean concentration as output from MAMPEC-BW = called average in the MAMPEC-BW results calculated.

7.2 Predicted No-Effect Concentration

PNEC is determined by all the ecotoxicological studies that have earlier been performed for the specific substance considering all species tested, marine and freshwater as well as results of acute and chronic tests. The quality of the ecotoxicological data is also taken into account. For a high-quality PNEC, a complete dataset is needed. A dataset is considered complete when there are at least three chronic tests available for three different aquatic species of three different trophic levels, e.g., fish, crustaceans and algae. If the dataset is not complete, the quality of the extrapolation to a PNEC is lowered and an additional assessment factor (AF) is taken into account to compensate for the lower quality. Generally, ecotoxicological studies with marine organisms are preferred, but the tests performed with the substances under consideration are mostly carried out with freshwater organisms. Comparisons of ecotoxicity studies with freshwater organisms and marine organisms did not show any significant statistical difference (Slooff et al. 1986). Therefore, all ecotoxicity tests carried out are

included in the final dataset that determines which AF should be used for the estimation of PNEC. In Table 3, the AFs used in different situations are given.

Table 3 Assignment of Assessment Factors (AF) used for deriving PNEC values

Dataset	**Assessment Factor (AF)**	
	$PNEC_{harbour}$	**$PNEC_{nearship}$**
Lowest* short-term $L(E)C_{50}$ from freshwater or marine species representing one or two trophic levels	10,000	1000
Lowest* short-term $L(E)C_{50}$ from three freshwater or marine species representing three trophic levels	1000	100
Lowest* short-term $L(E)C_{50}$ from three freshwater or marine species representing three trophic levels + at least two short-term $L(E)C_{50}$ from additional marine taxonomic groups	100	10
Lowest* chronic NOEC from one freshwater or marine species representing one trophic level, but not including micro-algae	100	–
Lowest* chronic NOEC from two freshwater or marine species representing two trophic levels, which may include micro-algae	50	–
Lowest* chronic NOEC from three freshwater or marine species representing three trophic levels, which may include micro-algae	10	–

L(E)C50 = lethal (effect) concentration for 50% of the test organisms
NOEC = no-effect concentration for the test organism
Notes:*1. If the lowest value is not used, based on expert judgement, a scientific rationale should be submitted
2. AF assigned to chronic data may be lowered if sufficient (for instance three different trophic levels) acute values are available

3. See Sect. 3.3.3 of the Methodology for information on suitable chronic testing

$PNEC_{harbour}$ is used for the RA for the whole harbour and $PNEC_{nearship}$ is used for the local situation close to the discharge point of the ballast water from the ship.

7.3 PEC/PNEC

The ratio between the resulting PEC for the harbour and for the area close to the ship from MAMPEC-BW calculation, and the corresponding PNEC, is calculated. In cases where the result is below 1, the assumption is that no unacceptable risk will result from exposure to that chemical. At BA evaluation stage, PEC/PNEC evaluation prevails over the laboratory ecotoxicity tests (Whole Effluent Toxicity (WET) tests). GESAMP-BWWG generally accepts that PEC/PNEC ratios for some chemicals exceed 1. The applicant is, nevertheless, encouraged to address this point in any future application for FA. At the FA evaluation stage, the results of the WET tests are regarded to be of higher importance, such that in the case where results from the WET tests only show slight toxic effects (less than a factor of 5), PEC/PNEC ratios above 1 may be considered acceptable.

The concentration calculated with the near-ship RA formula will be compared to acute toxicity data for ASs and Relevant Chemicals to evaluate the short-term effects on aquatic organisms, according to the ratio:

$$\mathbf{PEC_{nearship}/PNEC_{nearship}} \qquad (15)$$

7.4 Whole Effluent Toxicity Tests

The most important part of FA submission are the results from the WET tests. In general terms, RA deals with one substance at a time when in reality aquatic organisms are exposed to a mixture of substances. The advantage of WET

testing on the ballast water discharge is that it integrates and addresses the potential aquatic toxicity of AS, any Preparations, including any of its components, e.g., decomposed chemicals like isocyanuric acid, and Relevant Chemicals formed during and after application of BWMS (such as DBPs).

8 Human Health: General Public

8.1 Exposure Scenarios for the General Public

Direct exposure of humans may occur by swimming (inhalation, dermal exposure and swallowing water) in the harbour or the surrounding area and indirect exposure via the environment where treated ballast water is discharged as well as by consumption of seafood. As a general principle, consumer exposure is normally assessed as being chronic and thus taking place throughout the whole lifetime in order to protect the most vulnerable population groups.

The following situations have been identified as likely exposure scenarios for the general public and have been regarded as worst-case exposures as shown in Table 4.

Table 4 Summary of exposure scenarios for the general public to treated ballast water containing DBPs as a worst-case scenario (IMO 2017)[a]

Scenario	Exposure	Duration/quantity
Recreational activities in the sea	Inhalation of chemicals partitioning into the air above the sea	5 events of 0.5 hours/day for 14 days of the year
	Dermal exposure to chemicals whilst swimming in the sea	5 events/day for 14 days of the year
	Swallowing of seawater contaminated with treated ballast water	5 events of 0.5 hours/day for 14 days of the year

Scenario	Exposure	Duration/quantity
Eating seafood exposed to treated ballast water	Oral consumption	Once or twice/day equivalent to 0.18 kg/day

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Aggregated exposure (through swimming and consumption of seafood)

A number of assumptions is being used in the human exposure scenarios for general public. The assumptions being used are listed in Table 5. In all scenarios, default parameters leading to worst-case assessment are applied. Accordingly, the body surface area of males is assumed, but the body weight of women (60 kg) is applied. The surface area of the exposed skin for hands (front and back) for males is 0.084 m^2 (ECHA 2016) and the whole body surface area for men is 1.94 m^2. One parameter, the ingestion rate of water while swimming, is taken from the Swimodel (US EPA 2003). The quantity of seafood consumed daily was selected from the Food and Agricultural Organization (FAO) statistics on fish consumption (FAO 2003).

Table 5 Summary of physiological parameters in human exposure scenarios for general public (modified after IMO 2022a)

Parameter	Value	Reference
Body weight	60 kg	ECHA (2017)
Whole body, surface area	1.94 m^2	US EPA (1997)
Inhalation rate (light activity)	1.25 $m^3\ h^{-1}$	ECHA (2017)

Parameter	Value	Reference
Ingestion rate of water while swimming	0.025 L h^{-1}	US EPA (2003)
Quantity of seafood consumed	0.18 kg d^{-1}	FAO (2003)
Temperature	293 K	GESAMP-BWWG assumption
Dilution factor, swimming	100	EUSES (2016)

8.2 Recreational Activities (Swimming in the Sea)

8.2.1 Inhalation of Chemicals Partitioning into the Air Above the Sea

Exposure in this scenario is through inhalation of air above the sea while swimming. The concentration of chemicals in the air may be calculated using Henry's Law constant as described in Eq. (16).

$$C_{\text{air}} = \frac{H}{R \cdot T} \cdot C_{\text{water}} \tag{16}$$

C_{air} = concentration in air (mg m^{-3})
H = Henry's Law constant (Pa m^3 $mole^{-1}$)
R = gas constant (8.314 Pa m^3 $mole^{-1}$ K^{-1})
T = absolute temperature (K) (default = 293 K)
C_{water} = measured concentration in ballast water (µg L^{-1})

In this case, however, the concentration in the water is PEC harbour value as calculated by MAMPEC and taking into account a dilution factor of 100 (due to wind, turbulence and insufficient time for the chemical to reach equilibrium) (EUSES 2023). It should be noted that this scenario is not realistic in practice since the general public are usually not swimming in these types of ports, only specialized divers are likely to swim in the port. However,

there are also ports where a beach is just across a port terminal.

The inhaled dose may be estimated using the equation below, taking into account various assumptions (number of swims, etc.):

$$\mathrm{Dose_{Inh}} = \frac{C_{\mathrm{air}} \cdot IR \cdot n \cdot D \cdot \mathrm{Bio_{inh}} \cdot 1000}{\mathrm{BW}} \qquad (17)$$

$\mathrm{Dose_{Inh}}$ = inhalation intake of chemical during swimming (mg $\mathrm{kg^{-1}_{bw}}$ $\mathrm{d^{-1}}$)

C_{air} = concentration in air (mg $\mathrm{m^3}$)

IR = inhalation rate – light activity assumed (1.25 $\mathrm{m^3}$ $\mathrm{h^{-1}}$)

n = number of swims per day (5 $\mathrm{d^{-1}}$)

D = duration of each swim (0.5 h)

$\mathrm{Bio_{inh}}$ = fraction of chemical absorbed through the lungs (default = 1)

BW = body weight (default = 60 kg)

8.2.2 Dermal Exposure to Chemicals While Swimming in the Sea

Exposure in this scenario is via dermal uptake of chemicals when swimming, using the following equation:

$$\mathrm{Dose_{Der}} = \frac{C_{\mathrm{water}} \cdot \mathrm{TH_{dermal}} \cdot n \cdot A_{\mathrm{skin}} \cdot \mathrm{Bio_{dermal}} \cdot 1000}{\mathrm{BW}} \qquad (18)$$

$\mathrm{Dose_{Der}}$ = dermal uptake per day during swimming (mg $\mathrm{kg^{-1}_{bw}}$ $\mathrm{d^{-1}}$)

C_{water} = concentration in the water, i.e., $\mathrm{PEC_{MAMPEC\text{-}BW}}$ (µg $\mathrm{L^{-1}}$)

$\mathrm{TH_{dermal}}$ = thickness of the product layer on the skin (0.0001 m)

n = number of swims per day (5 $\mathrm{d^{-1}}$)

A_{skin} = surface area of whole body being exposed to water (1.94 m^2)
Bio_{dermal} = bioavailability for dermal intake (default = 1)
BW = body weight (default = 60 kg)
Note: the subscript BW in line 2 means Ballast Water, in the last line BW is body weight.

8.2.3 Swallowing of Water Contaminated with Treated Ballast Water

The oral uptake via swimming is calculated according to the following equation:

$$\mathrm{Dose_{Oral}} = \frac{C_{water} \cdot \mathrm{IR_{swim}} \cdot n \cdot \mathrm{Dur_{swim}} \cdot \mathrm{Bio_{oral}}}{\mathrm{BW}} \quad (19)$$

$\mathrm{Dose_{Oral}}$ = amount of chemical swallowed (µg kg^{-1}_{bw} d^{-1})
C_{water} = concentration in the water, i.e., $PEC_{MAMPEC\text{-}BW}$ (µg L^{-1})
IR_{swim} = ingestion rate of water while swimming (0.025 L h^{-1})
n = number of swims per day (5 d^{-1})
Dur_{swim} = duration of each swim (0.5 h)
Bio_{oral} = bioavailability for oral intake (default = 1)
BW = body weight (default = 60 kg)

8.3 Eating Seafood Exposed to Treated Ballast Water

The concentration of chemicals in seafood that is being consumed is calculated according to the following equation:

$$C_{fish} = \mathrm{BCF} \cdot C_{water} \quad (20)$$

C_{fish} = concentration in fish (µg kg^{-1})
BCF = bioconcentration factor (L kg^{-1})

C_{water} = concentration in the water, i.e., $PEC_{MAMPEC\text{-}BW}$ ($\mu g\ L^{-1}$)

The calculation of concentrations in seafood has to be carried out for all ASs and relevant chemicals. The cut-off value for the bioconcentration factor, as described for the environmental RA (IMO 2017), is not applicable in the RA for human health. Making the assumption that people in the area only eat fish that is being caught locally as a worst-case scenario, the daily intake may be calculated using the following equation:

$$\mathrm{Dose}_{fish} = \frac{\mathrm{QFC} \cdot C_{fish} \cdot \mathrm{Bio}_{oral}}{\mathrm{BW}} \tag{21}$$

Dose_{fish} = uptake of chemical from eating fish ($\mu g\ kg^{-1}{}_{bw}\ d^{-1}$)

QFC = quantity of fish consumed/day (= 0.18 kg d^{-1} (FAO 2003), Japan)

C_{fish} = concentration of chemical in fish ($\mu g\ kg^{-1}$)

Bio_{oral} = bioavailability for oral intake (default = 1)

BW = body weight (default = 60 kg)

8.4 Aggregated Exposure (Through Swimming and Consumption of Seafood)

The total exposure to the general public whilst swimming in the sea and eating seafood is the sum of the amount of chemical absorbed through eating fish plus the oral intake, dermal absorption and inhalation absorption whilst swimming. An indicative risk level is used to calculate an indicative RCR regarding potential cancer risk. These values can be used to estimate a risk dose based on the probability of increased cancer incidence over a lifetime (10^{-5}) and may be regarded as a DMEL for the general public.

At the most basic level, the standard chemical safety assessment accounts for uncertainty by using conservative assumptions and default values, for instance, following specific Tier 1 methods recommended in the exposure estimation (ECHA 2012). In the GESAMP-BWWG Tier 1 RA for the general public, it is assumed that exposure may occur through swimming in the water where the ballast water has been discharged or eating seafood that has been caught in the vicinity of a harbour where the ballast water was discharged. If an elevated risk to the general public is identified in Tier 1, a Tier 2 calculation may be performed by taking into consideration the assumption that activities take place in areas more remote to the actual harbour. For these calculations, the standard output from MAMPEC regarding the concentrations in the surrounding waters may be used. In a real-life situation, this is more likely to be the case; however, in some cases, such swimming may actually occur in the actual harbour.

9 DNEL/DMEL Derivation

In assessing an acceptable level of a particular substance, the procedure usually follows moving from available toxicological data giving a no-observed-adverse-effect level (NOAEL) or a lowest-observed-adverse-effect level (LOAEL) to deriving an exposure limit above which humans should not be exposed (DNEL). AFs have to be taken into account to allow for extrapolation from experimental data to real human exposure situations (Tables 6 and 7). Carcinogens can have a threshold or non-threshold mode of action. When it comes to threshold carcinogens, these can be assessed by using a DNEL approach.

Table 6 Default AFs (modified from ECHA 2012)

AF accounting for differences in		Default value systemic effect
Interspecies (ASF) (OSF)	Correction for differences in metabolic rate per body weight	AS[a,b]
	Remaining differences	2.5
Intraspecies (ISF)	Worker	5
	General public	10[c]
Exposure duration (SF_{dur})	Subacute to subchronic	3
	Subchronic to chronic	2
	Subacute to chronic	6

ASF = Interspecies Allometric Scaling Factor
OSF = Other Scaling Factor
ISF = Intraspecies Scaling Factor
SF_{dur} = Scaling Factor for test duration
[a]AS = factor for allometric scaling, see below
[b]Caution should be taken when the starting point is an inhalation or a diet study
[c]Not always covering for young children

Table 7 Allometric scaling factors for different species as compared to humans[a] (modified from ECHA 2012)

Species	Body weight (kg)	AS factor[a]
Rat	0.250	4
Mouse	0.03	7
Rabbit	2.00	2.4
Dog	18.00	1.4

[a]Not applicable when setting an inhalation DNEL based on an animal inhalation study

However, in the case of non-threshold carcinogens, a DMEL should be determined. Cancer risk levels from internationally recognized bodies, like WHO, FAO, JECFA,

EPA, EU, etc., are normally seen as indicative tolerable risk levels (in GESAMP-BWWG RA 10^{-5}, that is a risk for cancer in 1 per 100,000 exposed individuals is applied for the selection of DMELs).

9.1 Risk Characterization in the Human Exposure Scenarios

In the human RA, the exposure derived from the Human Exposure Scenarios (HES) is compared with the level above to which humans should not be exposed, DNEL and/or DMEL as already outlined above. The RCR is calculated by dividing the resulting aggregated exposure (for the relevant pathways/routes) for single chemicals by DNEL or DMEL, under the assumption that where the result is below 1, no unacceptable risk will result from the exposure to that chemical. Furthermore, group RCRs are calculated for chemicals that are identified as non-threshold carcinogens.

The total exposure to the general public whilst swimming in the sea and eating seafood is the sum of the amount of chemical absorbed through eating fish plus the oral intake, dermal absorption and inhalation absorption whilst swimming. The risk characterization ratio may be calculated by dividing the aggregated exposure by DNEL and/or DMEL values for each chemical (Eq. 13). If RCR_h is greater than 1, the conclusion is that a potential risk cannot be excluded and additional information may be required, while in the case that RCR_h is less than 1, a potential risk should be considered not present and the use of the BWMS should be regarded as safe for human health. In the example below (Table 8), all the RCRs in DNEL case are below 1, the same is the case for all individual chemicals in the DMEL case.

Table 8 Tier 1 RCRs for the general public calculated for the observed maximum concentrations of frequently occurring DBPs (based on values in

Table 2)

DBP	Aggregated exposure (µg kg^{-1} bw d^{-1})	DNEL (µg kg^{-1} bw d^{-1})	DNEL based RCR	DMEL (µg kg^{-1} bw d^{-1})	DMEL based RCR
Bromochloroacetic acid	1.1E-1	3.8E+2	3.0E-4	1.3E-1	8.8E-1
Dibromoacetic acid	6.9E-2	3.6E+1	1.9E-3	1.3E-1	5.3E-1
Dibromochloromethane	8.0E-2	1.1E+2	7.4E-4	1.5E+0	5.3E-2
Dichloroacetic acid	2.4E-2	6.0E+1	4.1E-4	1.7E+0	1.4E-2
Dichlorobromomethane	5.6E-2	2.5E+3	2.8E-3	1.7E+0	2.3E-2
Monobromoacetic acid	5.7E-2	3.5E+1	1.6E-3	NA	NA
Monochloroacetic acid	1.5E-1	3.5E+1	4.2E-3	NA	NA
Tribromoacetic acid	4.1E-1	4.3E+2	9.6E-4	NA	NA
Tribromomethane	7.1E-1	8.9E+1	7.9E-3	7.7E+0	9.2E-2
Trichloromethane	2.7E-1	1.2E+2	2.2E-3	NA	NA
Sum:					1.6E+0

NA = not available

The summed RCRs in DMEL case show a value greater than 1 (Table 8). When this is the case, a Tier 2 assessment may be performed by taking into consideration the assumption that the general public activities take place in areas more remote from the actual harbour. For these calculations, the standard output from MAMPEC-BW regarding the concentrations in the surrounding water may be used (Table 9).

Table 9 Tier 2 RCRs for the general public calculated for the observed maximum concentrations of frequently occurring DBPs (based on values in Table 2)

DBP	Aggregated exposure ($\mu g\ kg^{-1}\ bw\ d^{-1}$)	DMEL ($\mu g\ kg^{-1}\ bw\ d^{-1}$)	DMEL based RCR
Bromochloroacetic acid	1.2E-3	1.3E-1	9.6E-3
Dibromoacetic acid	7.6E-4	1.3E-1	5.8E-3
Dibromochloromethane	6.9E-4	1.5E+0	4.6E-4
Dichloroacetic acid	2.6E-4	1.7E+0	1.6E-4
Dichlorobromomethane	4.5E-4	1.7E+0	1.9E-4
Tribromomethane	6.4E-3	7.7E+0	8.4E-4
Sum:			1.7E-2

Since the DMEL-based RCR in Tier 2 is less than 1, a potential risk should be considered not present, and the use of the BWMS should be regarded as safe for human health.

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10 Discussion and Conclusions

The above-explained assessment of the use of AS in BWMS was prepared with the best knowledge at that time and based on discussions during the so-called Stocktaking Workshops (STW) of GESAMP-BWWG. The Guidelines (G9) were last amended in 2008 (IMO 2008) and the Methodology more recently in 2022 (IMO 2022a). GESAMP-BWWG was asked by MEPC 77 (MEPC 77/16) to hold another STW, which was held as its Ninth STW in 2022 (IMO 2022b). Items considered included three topics of which two were leftovers from earlier STWs and one new topic as a specific request of MEPC. The new topic was the development of guidelines for re-evaluations of Final Approval applications in cases where modifications have been made to a ballast water management system (Chap. 12 of the Methodology). The two remaining topics were TRO sensors (colorimetric and amperometric sensors equally acceptable) and recommended additional test

organisms for laboratory ecotoxicity testing as well as WET tests (none were recommended in addition). MEPC 78 endorsed the views of GESAMP-BWWG regarding all items considered at this workshop (IMO 2022c).

The GESAMP-BWWG initiated an investigation at GESAMP (one level up) on the global production and release of DBPs, taking into account not only ballast water but also cooling water, desalination, waste water treatment and seawater toilets. From all DBPs, only for tribromomethane (bromoform), a reasonable complete picture of the emission to the environment was possible. The contribution of industrial discharge of tribromomethane revealed a maximum of about 20×10^6 kg/a (Grote et al. 2022), compared to the emission from natural sources of this substance into the oceans was estimated at a rough estimate of 5×10^8 kg/a, which is about 4%. Other DBPs reached less than 4% from the contribution of tribromomethane. GESAMP concluded on the basis of these data that a further analysis of DBPs globally was considered neither possible nor feasible (GESAMP 2022).

During its evaluations of BWMS, GESAMP-BWWG considered that the Tier 2 approach of the human exposure scenarios was not sufficiently discriminative compared to Tier 1, as presented above. The distinction between Tier 1 and Tier 2 was spreading the exposure to ballast water contaminants over a lifetime period, which is especially relevant for the evaluation of carcinogenic substances, and some DBPs have carcinogenic properties. This approach is common in the toxicological evaluation of many substances and approved by, e.g., US EPA (1989). Table 2 gives a good illustration of the problem. The sum of the carcinogenic, mutagenic and toxic for reproduction substances (CMR) may become >1 in some cases. Therefore, GESAMP-BWWG

may need to develop a Tier 3 for this kind of substance. This could be best done during a STW.

Like all regulatory schemes for the risk assessment of chemicals, the methodology developed and used by GESAMP-BWWG is faced with the challenge to simplify a multitude of individual situations in such a way that they can be covered by a limited number of calculations. Otherwise, risk assessment would not be possible. In this process, a number of assumptions and estimations have to be made, which in some cases may be debatable (David et al. 2018; Dock et al. 2019, 2020). BWWG frequently evaluates its methodology, taking into account the latest available evidence. If the Group considers it justified, the standard assumptions in the Methodology are changed or complemented by additional considerations. This is evidenced by the fact that IMO has recently published the fifth revision of the original document (IMO 2022a).

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© Springer Nature Switzerland AG 2024
M. David, S. Gollasch (eds.), *Global Maritime Transport and Ballast Water Management*, Invading Nature - Springer Series in Invasion Ecology 16
https://doi.org/10.1007/978-3-031-48193-2_5

Compliance Monitoring and Enforcement of the Ballast Water Management Convention: The Port State Control Perspective

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Abstract
One of the very critical aspects for an effective implementation of the Ballast Water Management (BWM) Convention is the compliance monitoring and enforcement (CME) process. The BWM Convention provides basic requirements regarding inspections and consequences, while this process is further supported by IMO Port State Control (PSC) Guidelines and IMO G2 Guidelines on ballast water sampling (BWS). As the G2 Guidelines were recognized to lack details, further Guidance for BWS was prepared. Regional approaches under memoranda for PSC also started to develop. The latest research shows that there are still uncertainties, issues and unconformities that could penalize international shipping and on the other side it may weaken the BWM Convention implementation. CME under the BWM Convention was also recognized to be rather specific, introducing different principles and approaches than other IMO Conventions, which makes it even more challenging for PSC officers. In this chapter, we introduce the main aspects and specifics of CME of the BWM Convention, discuss related implementation issues and recommend the way forward.

Keywords BWM Convention implementation – Compliance monitoring and enforcement – Port State control – Maritime inspections – Ballast water sampling

1 Introduction

To ensure an effective implementation of the Ballast Water Management (BWM) Convention globally, Compliance Monitoring and Enforcement (CME) measures need to be implemented. The BWM Convention articles 9–12 provide elementary grounds for inspections, while more details on how to proceed with inspections are provided in the Guidelines for Port State Control (PSC) under the BWM Convention (PSC Guidelines) (IMO 2014), Guidelines for Ballast Water Sampling (G2) (G2 Guidelines) (IMO 2008) and the most up-to-date revision of the Guidance on ballast water sampling and analysis for trial use in accordance with the BWM Convention and Guidelines (G2) (IMO 2020).

Inspections are further organized under different regional agreements, so-called Memorandum of Understanding (MoU), where the inspection process may be further detailed/organized to their specifics. Almost all coastal States are included in some of the present nine MoUs, i.e., Paris MoU[1] (26 European countries and Canada), Tokyo MoU (Pacific Ocean), Acuerdo Latino or Acuerdo de Viña del Mar (South and Central America), the Caribbean MoU, the Mediterranean MoU, the Indian Ocean MoU, the Abuja MoU (West and Central Atlantic Africa), the Black Sea MoU and the Riyadh MoU (Persian Gulf), while United States (US) implement their CME activities through the US Coast Guard (USCG). Furthermore, there are also existing inspection regimes according to local port authority legislations.

Vessels entering ports have to meet the relevant reporting requirements of that jurisdiction. Vessels are attributed with a vessel risk profile which determines its priority for inspection. Based on that priority, PSC Officers (PSCOs)[2] are assigned for the inspection of that vessel. For the Paris MoU region, the requirement is for inspections to

be carried out by properly trained, qualified, officers who have been authorized under the national legislation of the port State authority concerned. In addition to the fixed profile targeting of vessels, PSCO reviews any unexpected factors and reports entered in their database and may conduct an inspection of a vessel on the basis of that information. PSCOs endeavour to detect and secure the rectification of all deficiencies with the relevant stakeholders, i.e., vessel's crew, Master, owner and flag State. If required, vessels may be allowed to proceed to a repair port/shipyard, provided that there is no outstanding risk to health, safety or the marine environment. If a vessel is found to present a risk that has not been rectified, PSCO may issue a detention order. If a vessel is detained, PSCO will engage with the stakeholders, notifying the flag State Administration of the vessel in writing and including a copy of the inspector's report. The banning (exclusion) of a vessel from a region/MoU ports, as the most stringent measure, only occurs after multiple detentions of that vessel in that region. By any of the authorities in a MoU, banning is the refusal of access of a vessel to ports in that MoU. A first banning usually lasts for a period of three months, and the vessel must be reinspected to allow a lifting of the ban. The period of the banning becomes more extended with subsequent bans. Before denying entry of a vessel due to it being banned, the port State authority may request consultation with the flag State Administration of that vessel. Authorities are required to report on the inspections and conclusions conducted in their jurisdiction to their MoU information system. That includes inspections conducted to confirm compliance with the BWM Convention.

This chapter provides a review of existing PSC measures, tools, procedures and systems to enable monitoring of vessels' compliance with the BWM

Convention, their discussion and conclusions with recommendations.

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2 BWM Convention as the Legal Framework for Inspections

The BWM Convention represents the main legal instrument for BWM and CME actions. The main requirements for inspection and control actions are included in Articles 9, 10, 11 and 12 (IMO 2004).

Under Article 9, inspections may be conducted in any port or offshore terminal by duly authorized officers to determine vessels' compliance with the BWM Convention. Such inspections may be as a first stage limited to verify the validity of the International Ballast Water Management Certificate (IBWMC), inspection of the Ballast Water Record Book (BWRB) and/or ballast water sampling (BWS). BWS is to be conducted according to the G2 Guidelines, while the vessels shall not be unduly delayed for the time to conduct sample analyses. When the vessel does not present a valid IBWMC, or there are clear grounds that BWM equipment does not correspond to IBWMC, and/or vessel's responsible crew is unfamiliar with the BWM procedures or has not implemented these, ballast water shall not be discharged until this could be done without representing a threat of harm to the environment, human health, property or resources.

Parties to the BWM Convention shall cooperate with the goal to detect violations and establish control of vessels (Article 10). A vessel that has been found to have violated the BWM Convention may be warned, detained or banned/excluded. The non-compliant vessel may also be left to leave the intended port or terminal to proceed to an appropriate location, reception facility or repair yard where ballast water could be safely discharged.

When BWS is conducted to check compliance in the present port, or this information is received from a previous port or terminal and the results indicate the vessel's non-compliance, this vessel shall not be left to discharge ballast water until the threat is removed.

Inspections may also be conducted when this is requested by another Party to the BWM Convention which presents enough evidence that the vessel is operating in violation. Inspection results are to be sent to the Party that requested the inspection and the vessel's flag Administration.

When a violation of the BWM Convention is detected, a notification of control actions is to be conducted (Article 11). The violating vessel shall be notified, and the report containing any evidence of violation shall be provided to the vessel's administration. Furthermore, the recognized organization responsible for the issuing of certificates shall be notified in cases when the vessel was banned from discharging ballast water or directed to another location where she could safely discharge ballast water due to detected violations. When no corrective action could take place, e.g., because a violation was identified after the vessel had already left the port, or the vessel was allowed to proceed to the next port of call, the next port of call shall be informed about the violation.

All possible efforts shall be made to avoid undue delay of vessels (Article 12). When unduly detained or delayed, the vessel shall be entitled to compensation for any loss or damage suffered.

Guidelines for Port State Control under the BWM Convention (PSC Guidelines) were adopted on 17 October 2014 by the Resolution MEPC.252(67) to provide basic guidance for the conduct of a Port State Control (PSC) inspection to verify compliance with the requirements of the BWM Convention (IMO 2014).

Guidelines for Ballast Water Sampling (G2) (G2 Guidelines) were adopted on 10 October 2008 by the Resolution MEPC.173(58) to provide Parties, including PSCOs, with practical and technical guidance on BWS and analysis for the purpose of determining whether the vessel is in compliance with the BWM Convention according to Article 9 “Inspection of Ships”. These Guidelines only address general technical sampling procedures and do not address legal requirements (IMO 2008).

Guidance on ballast water sampling and analysis for trial use in accordance with the BWM Convention and Guidelines (G2) (BWS Guidance) as per IMO BWM.2/Circ.42 on 24 May 2013 was agreed to provide general recommendations on methodologies and approaches for sampling and analysis to test for compliance with the standards described in regulations D-1 and D-2 of the BWM Convention. BWS guidance is to be considered in conjunction with the BWM Convention, the PSC Guidelines and the G2 Guidelines (IMO 2013). This Guidance was revised in 2015 (IMO 2015) by adding a method to the list of indicative analysis methods for use when testing for potential compliance with the D-2 standard. It was again revised in 2020 to add more details regarding indicative and detailed analysis methods and to add references (IMO 2020).

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3 BWM PSC Developments Through MoUs

Guidance to Port State Control Officers for verifying Compliance with the International Convention for the Control and Management of Ships’ Ballast Water and Sediments, 2004 (EMSA PSC Guidance) was adopted as Port State Control Committee Instruction 48/2015/13 (PSCC48/Annex 12) to provide basic guidance for the

conduct of a PSC inspection under the Paris MoU to verify compliance with the requirements of the BWM Convention. This EMSA PSC Guidance (Paris MoU 2015) is however not yet in force and is not public.

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4 CME Application Under the BWM Convention

The BWM Convention applies to all vessels, including semi-submersibles, floating offshore platforms, Floating Storage Units (FSUs) and Floating Production and Storage Units (FPSOs) designed or constructed to carry ballast water, entitled to fly the flag of a Party who is signatory to the convention and vessels not entitled to fly the flag of a Party but which operate under the authority of a Party (Article 3.1, Application). With this, the inspections are to be implemented through the PSC as well as the Flag State Control (FSC).

While CME application generally refers to the shipping industry, the General Obligations (Article 2) also refer to State responsibilities. Although all the obligations should be met, two are worth a particular mention due to their multi-jurisdictional nature. Article 2.6 states that Parties to this Convention shall endeavour not to impair their environment, human health, property or resources or those of other States. Further, Article 2.9 states that Parties shall endeavour to cooperate under the auspices of IMO to address threats and risks to sensitive, vulnerable or threatened marine ecosystems and biodiversity in areas beyond the limits of national jurisdiction in relation to BWM.

The BWM Convention is not applicable to ballast-free vessels, vessels engaged in national trade only, naval auxiliary or other vessels owned or operated by a State and used, for the time being, only on Government non-

commercial service and vessels fitted with permanent ballast water. Furthermore, a set of exceptions has been established by the Conventions (Article A-3) just to cover particular circumstances, such as emergency or accidental cases, or when the uptake and discharge is done in high seas or in the same location (Gollasch and David 2012; David et al. 2013a). Based on risk assessment (RA) conducted according to the 2017 Guidelines for risk assessment under regulation A-4 of the BWM Convention (G7) (IMO 2017a), vessels may also be exempted (Article A-4) from conducting BWM. Furthermore, in certain areas, the same risk area (SRA) concept may apply. In summary, the area which all selected species may be able to reach with their natural spread is seen as SRA, in which no BWM requirement applies for vessels sailing only in such an area. Vessels under exceptions, exemptions, as well as those under the SRA concept may also be inspected to ascertain their correct application (IMO 2017a; Outinen et al. 2021) (Fig. 1).

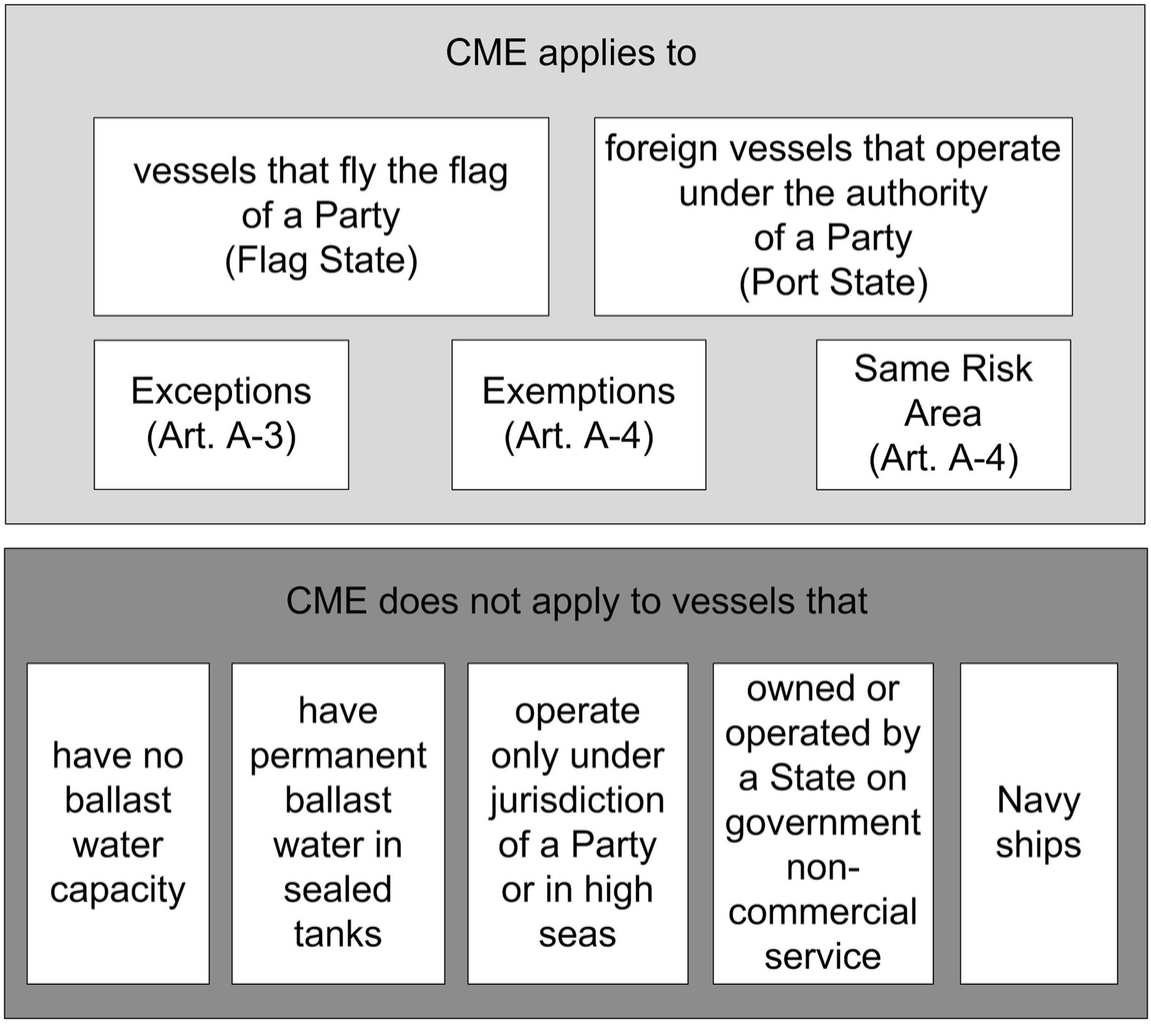
CME applies to
vessels that fly the flag of a Party (Flag State)
foreign vessels that operate under the authority of a Party (Port State)
Exceptions (Art. A-3)
Exemptions (Art. A-4)
Same Risk Area (Art. A-4)
CME does not apply to vessels that
have no ballast water capacity
have permanent ballast water in sealed tanks
operate only under jurisdiction of a Party or in high seas
owned or operated by a State on government non-commercial service
Navy ships

Fig. 1 Compliance Monitoring and Enforcement (CME) under the BWM Convention

5 Decision on When to Conduct an Inspection

As a first step of CME process, a vessel selection process needs to be conducted. In general, if under a MoU, PSC has a separate BWM-specific CME programme in place, a random selection with a minimum number of vessels to be targeted may be conducted. Furthermore, vessels may be targeted based on the risk being posed by the ballast water to be discharged to the recipient environment (David 2007; David et al. 2015a). It is actually very important to

understand that the general inspection triggering elements like vessel age, flag, past deficiencies, etc. do not encompass one of the most critical points in the ballast water issue, which is the risk being posed by the ballast water to be discharged. Meaning, when a vessel with low-risk ballast water may be targeted for PSC, while the one with critical ballast water is missed out, the main goal of providing for human health, resources and environmental protection may not be achieved. Hence, it is very important to have a BWM-specific CME programme. However, if this is not available, then PSC may select a vessel for BWM CME process while carrying out an inspection as per the already implemented regular vessel inspection programme.

According to Article 9 of the BWM Convention, a vessel to which the BWM Convention applies may be subject to inspection in any port or offshore terminal of the port State that is Party to the BWM Convention. According to the BWM Convention, the verification process has two levels, and the triggering elements may be grouped accordingly. Each of these triggers the compliance monitoring process directly or randomly. A vessel which is targeted by the selection process enters CME process.

The two levels of the verification process are the “initial inspection” and the “detailed inspection”. The main differences between the two levels are the triggering elements and the consequences for the vessel during the inspection process. Neither the BWM Convention nor the PSC Guidelines specify the vessel selection process for inspections, but this is generally defined under a PSC MoU. However, the BWM Convention specifies triggering elements for the detailed inspection, which are based on identification of discrepancies/non-compliance in the initial inspection.

In general, the initial inspection does not require special justification for its triggering elements and as such can be understood as part of the basic and regular PSC inspection

process. However, to improve CME process, a vessel may be targeted for initial inspection when:

- there is a defined minimum number of vessels to be checked for compliance with the BWM Convention, i.e., under a regular BWM verification process;
- PSCO conducts inspection under a separate process and becomes suspicious also for BWM compliance;
- the vessel is found not trustworthy based on compliance history;
- when available, a ballast water discharge assessment (BWDA) may be conducted in advance based on the ballast water reporting form (BWRF), and reporting of ballast operation may be found not trustworthy; or,
- there is a request for an investigation received from any Party and sufficient evidence of violation of BWM Convention is provided.

The initial inspection may be divided into a simple paper inspection and BWS for compliance. The simple paper inspection includes:

- a verification that there is a valid IBWMC on board the vessel;
- an inspection of BWRB; and,
- a verification that responsible crew are familiar with essential shipboard procedures relating to BWM and that have implemented these.

Depending on which BWM standard the vessel needs to meet, the BWS for compliance needs to be conducted in two different ways:

- BWS for salinity (D-1 standard compliance); and.
- BWS for compliance with the D-2 standard.

BWS for salinity is generally used for a verification of BWE process, and specifically for the verification of the RA process in cases when a decision taken was based on

environmental matching salinity. BWS for D-2 standard compliance requires analyses of viable aquatic organisms present in the ballast water to be discharged.

If BWS is conducted as part of the vessel inspection, the vessel shall not be unduly delayed for the time required to analyse the ballast water samples taken.

According to the BWM Convention, PSCO may decide to carry out a detailed inspection when a vessel:

- has no valid IBWMC;

or there are clear grounds to believe that:

- a certificate review results in the situation that the condition of the vessel or its equipment does not correspond substantially with the particulars of the certificate; or,
- the master or the crew are unfamiliar with essential shipboard BWM procedures, or these procedures were not implemented; or,
- the vessel is not carrying properly filled BWRB; or,
- the vessel does not have a designated Officer for BWM.

Furthermore, a vessel may be targeted for detailed inspection when:

- PSCO received notification that the vessel was found non-compliant with D-2 standard in a previous port after detailed BWS was conducted; or.
- any ballast water intended for discharge is identified as “high or very high risk” by the ballast water RA (BWRA) model (see David and Gollasch 2016).

It should be noted that there may be a lack of data to support the full implementation of BWRA process, as this data would need to be available about the ballast water origin/donor ports. Nevertheless, RA targets the core of the ballast water issue, and the BWRA at present at least gives an indication on RA situation related to the ballast water

intended to be discharged, while the precision of RA is to be improved in the future.

The detailed inspection includes, as appropriate:

- the inspection of all required documents and logbooks;
- the inspection of the vessel and BWMS; and/or,
- BWS for compliance (possibly apply indicative BWS and analysis, without any ballast water discharge).

According to Articles 9.2, 9.3 and 10.2, when a PSCO decides to carry out the detailed inspection using their professional judgement, or when BWS during initial inspection indicated non-compliance, or non-compliance is communicated by another Party, ballast water shall not be discharged from that vessel until it is proven that it can discharge ballast water without risks of harm to the environment, human health, property or resources.

It should be noted that, differently from all the other IMO Conventions, the BWM Convention establishes immediate mitigation measures to be taken by the PSCO, even just at the conclusion of the initial inspection. Furthermore, it should be noted that the order to stop deballasting may introduce a range of safety issues since it could affect the stability of the vessel in general and make interference with normal shipboard operations, including loading and unloading of cargo in particular (David et al. 2016).

The recommended vessel selection for CME process is presented in Fig. 2, including the two different levels of inspection according to the BWM Convention, i.e., the initial and the detailed inspection.

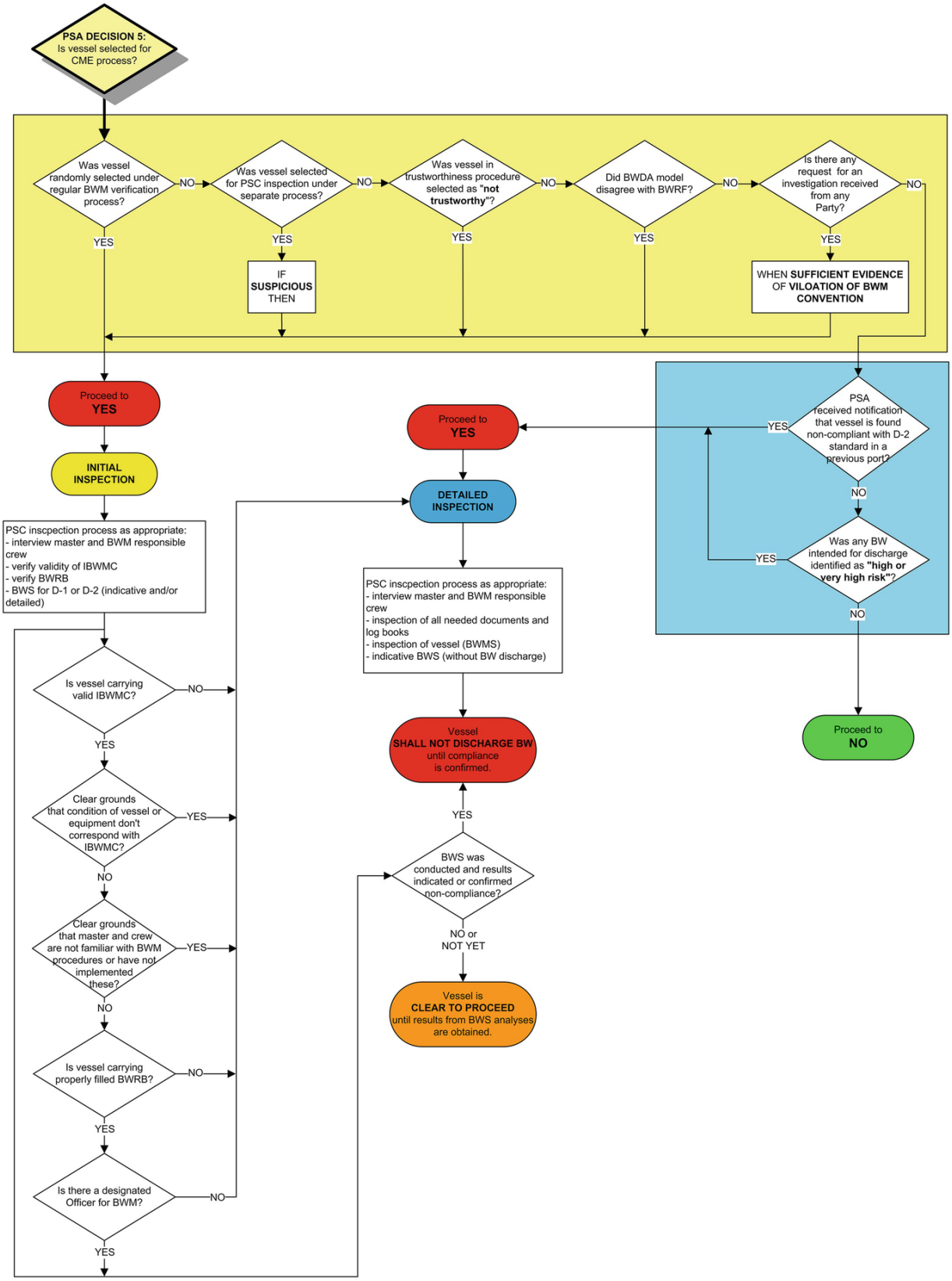
PSA DECISION 5:
Is vessel selected for CME process?
Was vessel randomly selected under regular BWM verification process?
NO
Was vessel selected for PSC inspection under separate process?
NO
Was vessel in trustworthiness procedure selected as "not trustworthy"?
NO
Did BWDA model disagree with BWRF?
NO
Is there any request for an investigation received from any Party?
NO
YES
YES
YES
YES
YES
IF SUSPICIOUS THEN
WHEN SUFFICIENT EVIDENCE OF VILOATION OF BWM CONVENTION
Proceed to YES
INITIAL INSPECTION
PSC inscpection process as appropriate:
- interview master and BWM responsible crew
- verify validity of IBWMC
- verify BWRB
- BWS for D-1 or D-2 (indicative and/or detailed)
Is vessel carrying valid IBWMC?
NO
YES
Clear grounds that condition of vessel or equipment don't correspond with IBWMC?
YES
NO
Clear grounds that master and crew are not familiar with BWM procedures or have not implemented these?
YES
NO
Is vessel carrying properly filled BWRB?
NO
YES
Is there a designated Officer for BWM?
NO
YES
Proceed to YES
DETAILED INSPECTION
PSC inscpection process as appropriate:
- interview master and BWM responsible crew
- inspection of all needed documents and log books
- inspection of vessel (BWMS)
- indicative BWS (without BW discharge)
Vessel SHALL NOT DISCHARGE BW until compliance is confirmed.
YES
BWS was conducted and results indicated or confirmed non-compliance?
NO or NOT YET
Vessel is CLEAR TO PROCEED until results from BWS analyses are obtained.
PSA received notification that vessel is found non-compliant with D-2 standard in a previous port?
YES
NO
Was any BW intended for discharge identified as "high or very high risk"?
YES
NO
Proceed to NO

Fig. 2 Vessel selection process for BWM CME, including the initial and the detailed inspection elements. The light yellow box includes elements that trigger the initial inspection; the light blue box includes elements that directly trigger the detailed inspection (edited after David and Gollasch 2021)

6 Ballast Water Sampling for CME

BWS for CME should be carried out according to the Guidelines for ballast water sampling (G2) (IMO 2008), also considering its related guidance document (IMO 2020). It should be noted that according to the BWM Convention, BWS may occur anytime, with or without other checks.

For BWS for compliance with the D-1 standard, in-tank or in-line samples may be taken to either prove the presence of coastal biota or check the water parameters. Salinity values verify if the water has been exchanged according to the BWM Convention requirements, i.e., in cases where the salinity is low (e.g., below 30 psu) it can be assumed that the ballast water originates from coastal areas with freshwater influence, i.e., it was not exchanged with ocean water (i.e., outside 50 or 200 nautical miles from nearest land and at water depths higher than 200 metres (IMO 2004)) as in these locations it would have a higher salinity (~35 PSU and higher). However, this is a feasible option only when the inspected vessel has loaded ballast water in a low salinity or freshwater port. For this purpose, small quantities of ballast water may be measured or sampled from the tank via sounding pipes or manholes or from the in-line BWS point prior to its discharge, preferably at multiple depths to avoid salinity stratification bias. The problem with the in-line BWS is that a discharge to sea may occur during BWS event, and in case of non-compliance, the non-complaint water would enter the recipient environment during the sampling event. However, in-line BWS may be conducted also during transfer of

ballast water from one tank to another if BWS point is in a position allowing this. Mostly this would not be possible considering that BWS points are to be installed as close as possible to an overboard discharge point.

BWS for compliance with the D-2 standard may be conducted as indicative or detailed (representative) BWS. The G2 Guidelines (IMO 2008) do not address explicitly how an indicative sampling for the D-2 standard would need to be undertaken, only indicative analysis is addressed. Implicitly, an indicative analysis could be performed on a sample, or part of it, taken during the detailed D-2 standard compliance control sampling process, or just on any (indicative) stand-alone sample. For indicative in-tank sampling, it was concluded that sampling for zooplankton via the sounding pipes does not result in a representative sample of species in the tank, as comparisons of sounding pipe and manhole samples from the same tank found that net samples taken via manholes delivered more biologically diverse samples (Sutton et al. 1998; Gollasch et al. 2000). Further, pumps used via open manholes delivered more diverse samples than net samples, therefore pumps may also be considered when sampling via manholes (Sutton et al. 1998; Gollasch et al. 2003). A problem is that frequently manholes cannot be opened due to, e.g., overlaying cargo or ongoing cargo operations in the area where the manhole is located, and in these instances, sounding pipe sampling might be the only solution to sample the ballast water at all. When applying indicative in-line (at discharge) sampling, it is recommended that one sequential sample is taken using the same sampling methodology as for a detailed D-2 standard compliance test. However, having in mind that indicative sampling may also be used for an early indication of potentially non-compliant ballast water and consequently to apply appropriate management measures, one key problem remains, and this is that compliance or non-

compliance can, in this scenario, only be proven while the ballast water is being pumped overboard. Tank-to-tank transfer may be conducted if in-line BWS is possible and BWM process is completed. Should, e.g., a risk assessment result in the identification of high-risk ballast water to be discharged, the in-line sampling during discharge should be avoided, but in-tank sampling should be undertaken to assess compliance. The in-tank sampling is only relevant when BWM process is fully completed.

To prove compliance with the D-2 standard, detailed sampling is to be conducted. The samples should be taken from the ballast water discharge line as near to the point of discharge as practicable, during ballast water discharge whenever possible, and be representative of the whole discharge. Although in-line sampling seems most appropriate for assessing compliance with a discharge standard, in case the ballast water originates from a high-risk area, i.e., an area with a known occurrence of target species, samples may be preferably taken from the ballast tank prior to discharge. This enables non-compliance actions before ballast water is released into the recipient environment.

IMO agreed to a two- to three-year trial period after the BWM Convention entry into force (8 September 2017), the so-called Experience Building Phase, during which sampling and sample processing experience was gained. This may likely result in an update of the sampling guidance and other CME-related documents, as well as in a BWM Convention review.

More details about BWS for CME may be found in the first edition of this book, the chapter on Ballast water sampling and sample analysis for compliance control (Gollasch and David 2015), in the publication recommendations for representative ballast water sampling (Gollasch and David 2017), and in this book chapter “Ballast Water Sampling for Compliance Monitoring and

Enforcement of the BWM Convention: D-1 and D-2 Indicative Tests" (David et al. this book).

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7 Decision on Stopping Deballasting

In cases when a vessel is found non-compliant with BWM requirements, PSC may decide to stop the vessel from deballasting. This may have an immediate effect on loading operations; however, compliance with the legal acts has priority over commercial reasons.

This action may find grounds, especially in the BWM Convention Articles 9.3 and 10.3, and in addition, it may be supported by a RA, if available. If a vessel has already started deballasting non-compliant ballast water and the risk posed is unacceptable, and a vessel was selected for detailed inspection or BWS, results have identified non-compliance, this vessel shall be stopped from deballasting. Should a vessel be required to stop deballasting, PSCO will notify that vessel on possible alternative BWM options available. If feasible, the vessel should conduct alternative BWM options. If this is not possible, the vessel may have to leave this port without the expected full cargo operation.

In practice, if PSCO discovers an error during an initial inspection that extends into an operational concern, they will ask the Master to stop ballasting operations. That will allow further investigation into the area of concern and possibly resolve any issues. Some IBWMC errors may be rectified quite quickly. Errors in BWM Plan (BWMP) or BWRB require a more detailed investigation and would most likely result in a request to stop deballasting. The majority of recorded deficiencies currently relate to errors in the completion of BWRB, more specifically relating to ballast water exchange, followed by BWRB entries that relate to situations of equipment failure and how that is recorded. As a note, often shipping company instructions vary when compared to individual authority's expectations,

understanding and requirements when recording such circumstances. If during an inspection of a BWMS, the unit is showing an alarm, ballast water operation is also stopped to determine the cause and route for rectification. This may be listed as a deficiency, often with a text addition that the system was, e.g., put through a flush cycle, or sensor test cycle or that an additive was refilled. Most issues may be addressed quickly (Michael Kennedy, pers. comm.).

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8 Decision on Allowing the Discharge of Unmanaged Ballast Water

A theoretically possible situation to allow discharge of unmanaged ballast water is when no “regular” or alternative BWM options were implemented, and the vessel has:

- declared to carry unmanaged ballast water on board which is intended for discharge;
- done everything in her capability to comply with BWM requirements;
- been unable to conduct the requested regular BWM practice; as well as,
- been unable to conduct alternative BWM practices.

PSCO needs to decide whether or not to allow such a vessel to discharge unmanaged ballast water in the port or if she needs to be turned away. Such a decision could possibly be taken according to the risk posed by the ballast water intended for discharge, i.e., when RA is available and low risk is identified. However, for the general practice and effectiveness of BWM measures, it is also important to take into account that the vessel did everything in her capability to comply with BWM requirements. In this situation, PSC should check:

- BWM requirements according to the legislation;

- vessel BWM options according to BWM plan;
- vessel intended route;
- voyage duration and other conditions;
- vessels capability to conduct alternative BWM options; and,
- RA result, when available.

In cases when a vessel took all measures to comply with BWM requirements, including alternative BWM options, the level of risk posed by the ballast water intended for discharge needs to be evaluated. If the ballast water was assessed as very high or high risk, the vessel should not be allowed to discharge ballast water. However, in cases when the risk level was assessed as intermediate, the vessel may still be allowed to discharge ballast water.

Certainly, it should be understood that these are only minimum criteria. It will be up to each PSCO to make a decision whether or not a more stringent approach has to be applied and possibly not to allow discharges of unmanaged ballast water that was assessed as high risk or even intermediate risk; this would be desirable especially when considering BWM from an environmental perspective.

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9 PSC Dilemma

Noting the above situations, PSCO may end up in a dilemma, which occurs in the cases when ballast water, which is intended for discharge, is identified as of high- or very high-risk condition. From an environmental protection standpoint, i.e., the view with which the BWM Convention was drafted, no such ballast water should be discharged to the environment until it was shown that can do so without presenting a threat of harm to the environment, human health, property or resources. However, use of RA is not explicitly stipulated for this purpose in the BWM Convention.

As a compromise, the situation where vessels should not discharge ballast water may be limited to high- and very high-risk situations, and only for those vessels where compliance with the D-2 standard is not confirmed. As no high- or very high-risk ballast water is permitted to be discharged to the port, no detailed ballast water sampling is enabled for this compliance check as this could be done only during discharge with samples taken from an in-line sampling point located close to the discharge point from the vessel. However, indicative ballast water sampling can be done with a sample taken from the tank directly, i.e., without discharging ballast water, although this may also be applicable only when the entire treatment process has been completed. In case this indicative sampling results do not indicate or give clear grounds for non-compliance with the D-2 standard, ballast water can be discharged, and during the discharge, a detailed sample may be taken to confirm the indicative sampling result. Should the indicative sampling indicate or give clear grounds for non-compliance with the D-2 standard, the ballast water cannot be discharged to the environment until compliance is confirmed. Should it be impossible to document compliance and no mitigation measures like use of ballast water reception facilities and neither any emergency treatment with active substances can be done, this ballast water shall not be discharged according to the BWM Convention. However, when all options for managing ballast water on the vessel and in the port were considered and consumed, and no mitigation measure is available, then the minimum amount of ballast water necessary for the vessel to complete the intended operation in the port may be allowed to be discharged. This is clearly against environmental protection principles, hence Parties would need to consider providing in the future for some option to manage high- or very high-risk water in such cases.

10 Decision on Issuing a Penalty

National legislation needs to include provisions to prevent improperly managed ballast water to be discharged, i.e., unwanted impacts caused by discharges of HAOP with ballast water. If a violation is detected, PSCO should evaluate whether or not national legislation has provided for such an act and has to proceed accordingly. The sanctions implemented should be of adequate severity to discourage further violations.

11 Discussion and Conclusions

The BWM Convention, as the main legal instrument for BWM and CME, has shown to be very complex and specific in its implementation. Essentially it requires the cooperation of parties globally and regionally, especially in situations where several jurisdictions are located along a regional sea. Here, a harmonized CME application approach is supporting the avoidance of confusions regarding which jurisdiction requires a certain approach. Also, the approach chosen may be different than in a neighbouring jurisdiction, which is especially critical to avoid additional burden on shipping and to provide for more effective implementation of BWM Convention measures.

The BWM Convention also provides for exceptions and exemptions, under which vessels may not need to conduct BWM. Nevertheless, such vessels may also be inspected to ascertain their correct application. To our knowledge, A-4 exemptions using the SRA concept are developing in several areas, e.g., in Singapore, Southeast Asia and the Chinese seas (IMO 2016a, 2019), and have already been agreed in the western Baltic between Sweden and Denmark (IMO 2016b, 2018). In contrast, IUCN stated that SRA

cannot be an option for the North Sea due to the inhomogeneous hydrological conditions (IMO 2017b). The western Baltic example is the Öresund SRA between Sweden and Denmark. BWM exemptions have been granted to five ships operating between Helsingborg (Sweden) and Helsingör (Denmark). The exemptions are valid for five years, starting in September 2021, and are subject to intermediate review (HELCOM 2021). Sweden and Denmark informed IMO about their SRA agreement (IMO 2022a).

Inspections organized under different regional agreements, MoUs, further detail/organize the process to their specifics. From an analysis of the reports submitted to MEPC sub-committee on Implementation of IMO Instruments (III) at IMO from MoUs on PSC, ballast water inspections seem to be under-reported for the Paris and Tokyo MoUs. The rest of the MoUs' reports show significantly less than the Paris/Tokyo MoUs, and a number of the smaller ones from developing countries do not even list ballast water as something they inspect.

The guidance on methodologies is there, but the reality of how the Member States who have ratified the Convention operate is completely different. Many countries satisfy their national Legislative requirement in a very minimal way. That is an Initial Inspection of the paperwork, certificates, plan and record book. If all is in order, then the inspector moves on. Other countries are more deliberate in their activities. They will conduct an indicative sample (generally in a narrow organism size search range) and have the ability to ramp-up to full.

There are also existing inspection regimes according to local port authority legislations. Such a case is, e.g., the Port of Hamburg. According to paragraph 13 of the Port Traffic and Shipping Act (Hafenverkehrs- und Schifffahrtsgesetz) in the Port of Hamburg, Duly Officers of the Water Police (Wasserschutzpolizei) are authorized to

inspect any vessel to investigate if BWM rules were followed. Legally, these inspections are limited to the examination of documents, logbooks, etc. But once an Officer is obtaining any doubts, for example in record-keeping, further steps, such as sample-taking, are the following consequences.

When implementing CME process, one of the critical steps becomes vessel selection for inspection. This seems to be still a very much overlooked process in terms of having inspection triggering points related to the ballast water risk level. Actually, to our knowledge, none of the MoUs at present has taken up ballast water related triggering elements. Consequently, vessels are still selected for inspection based on ship safety elements, which does not tell much/anything about the risk of the ballast water to be discharged, which is crucial element targeted by the BWM Convention. Meaning, if there is no risk, there is no need for protective measures, and the opposite. To this end, different studies were conducted, and RA models were developed (e.g., David 2007; David et al. 2013b, 2015b) to support such processes. These could best be implemented through a regional/MoU approach as part of BWM Decision Support System (David and Gollasch 2018).

To overcome some of the weaknesses as outlined above, IMO initiated an Experience Building Phase to permit MEPC to generally assess the effectiveness of the BWM Convention, identify any emerging problems and inform the subsequent review of the Convention. The data collection phase was completed in 2021 (IMO 2021) and the data crunching was completed (IMO 2022b). Key findings included:

- Twenty-one flag States submitted data including 16,199 ships to which the Convention applies. Of these, 13,971 ships were subject to regulation D-2 at the time of

reporting. Flag States reported that 7329 ships were fitted with a type-approved BWMS. Of the known types of installed BWMS, 93.6% of systems used either ultraviolet irradiation (UV) or electro-chlorination, and both hold a relatively balanced split of 49.7% for UV and 43.9% for electro-chlorination.

- Flag States provided data from 45,710 surveys conducted, with a total of 512 deficiencies, representing an estimated minimum 98.9% rate of compliance (based on a conservative estimate of one deficiency per survey). Mechanical, electrical, treatment process and maintenance/cleaning-related failures were the most commonly reported known deficiencies.
- 758 accidents and defects related to BWM operations (regulation E-1.7 of the BWM Convention) were reported, along with seven additional safety incidents related to BWM.
- The most frequently reported deficiencies were related to BWRB (greater than 70%), followed by crew not designated or unfamiliar with BWMS and no valid certificate on board.
- Fewer than 1% of inspections involved the collection and analysis of ballast water samples for compliance.
- Though data regarding actions arising from unsatisfactory inspections was limited, the submitted data indicated that, in nearly 97% of cases, information or advice was provided. Sanctions, warnings, detentions and prohibition of discharges made up approximately 3% of actions.
- Of the 123 detailed sampling events and analyses reported by Administrations, 68% were compliant with the D-2 standard. Data submitted by Administrations was generally consistent with data received from ballast water testing organizations: of reported tests by those organizations, 80% of commissioning tests and 78% of compliance tests met the D-2 standard.

- Failures to meet the D-2 standard were most common for the ≥50 µm organism size class. This size class was involved in 97% of failed compliance tests submitted by Administrations, 93% of failed compliance tests submitted by ballast water testing organizations and 81% of failed commissioning tests reported by testing organizations.
- In discharges compliant with the D-2 standard submitted by Administrations, concentrations of organisms were found to be significantly below the discharge standard, with averages below 1 organism/m^3 for the ≥50 µm size class and 2 organisms/mL for the 10–50 µm size class. Conversely, 61% of failures in the ≥50 µm size class were failures greater than ten times the discharge limit.
- In some cases, samples from discharges that had undergone ballast water exchange were analysed with respect to the D-2 standard. Despite limitations with small sample volumes, the reports suggest that only 33% of ships conducting ballast water exchange to comply with the D-1 standard had levels of organisms in discharged ballast water that could be considered in compliance with the D-2 standard (compared to 68% and 78% of discharges from ships using a BWMS as reported by Administrations and testing organizations, respectively). In 97% of the D-2 non-compliant cases, this was caused by organisms ≥50 µm. However, no definitive explanations for these failures to meet the D-2 standard could be provided.
- Approximately two-thirds of BWMS using Active Substances met the maximum allowable discharge concentration (MADC) requirement for residual oxidants during compliance testing. Administrations reported that 27% of discharges exceeded the MADC, while testing organizations reported that 34% of discharges exceeded the MADC (for testing organizations reporting

commissioning tests, only 8% of discharges exceeded MADC). This is of particular concern as an impact on the ballast water receiving waters is expected, which clearly is an unwanted effect. Further, this is in strong conflict with GESAMP-BWWG recommendations, i.e., that BWMS "application should include a control scheme showing that the Active Substance dose and MADC can be maintained effeectively in BWMS at all times, in particular at the beginning of discharge" (IMO 2022c).

- Of responses received from Administrations to the supplementary interface regarding feedback from ships' crews, 12.5% of ships' crews reported "difficulty with BWMS operation/maintenance in general" (19 out of 151 responses from ships installed with a BWMS, whether in use or not). This feedback from Administrations suggests a significantly lower frequency of difficulties than that reported in an industry survey, which reported that 77% of BWMS had problems or were not in good order.
- The three most common concerns from these surveys were the percentage of BWMS presenting operational problems, lack of sufficient crew training for BWMS, and insufficient vendor support for maintenance and calibration of BWMS.

It was further identified that crews are not well trained about how to adequately perform contingency measures when they have a BWMS failure (Oliver Jost, pers. comm.).

Considering the information received from Experience Building Phase, CME inspections are today mainly limited to documentation checks and crew familiarization with essential shipboard BWM procedures, including their implementation. This means that BWS, as an inspection tool provided by the BWM Convention, is not being used. It is important to note that BWS is actually the only way to verify biological performance against the D-2 Standard, as BWMS monitoring tools do not have this capacity. This is also confirmed through the experience with Commissioning

Tests according to BWM Circ.70. Rev.1, where almost all BWMS that failed in biological performance, their monitoring equipment did not show an irregularity (Stephan Gollasch and Matej David, pers. comm.). Representative BWS is not so trivial, and detailed analyses also require certain level of education and laboratory capacity, which is not available at responsible authorities that conduct PSC, which may be a reason that this is not yet being conducted. However, at present, there are different certified laboratories that regularly conduct such tests for the purpose of Type Approval and Commissioning testing, and these could also be used for CME purposes.

Based on the Experience Building Phase results, IMO is currently working on a Convention Review Plan, which will also consider associated guidelines and guidance documents. The BWM Convention review stage is expected to develop amendments through a systematic and evidence-based approach and ensure that amendments are developed holistically, taking into account any inconsistencies or ambiguities, through an objective, transparent and inclusive approach. The review may also consider any further information or data submitted to the Committee, and as such, interested parties are encouraged to collect and submit such information.

Ballasting operations may, in practice, be stopped if PSCO discovers an error during an initial inspection that extends into an operational concern. This will allow further investigation into the area of concern and possibly resolve any issues. Some IBWMC errors may be rectified quite quickly; however, errors in the BWMP or the BWRB require a more detailed investigation and would most likely result in a request to stop deballasting. The majority of recorded deficiencies currently relate to errors in the completion of BWRB, more specifically relating to ballast water exchange. Followed by BWRB entries that relate to situations of equipment failure and how that is recorded. As a note,

often shipping company instructions vary when compared to individual authority's expectations, understanding and requirements when recording such circumstances. If during an inspection of a BWMS the unit is showing a critical alarm, ballast water operation may also be stopped to determine the cause and route for rectification. This may be listed as a deficiency, often with a text addition that the system was, e.g., put through a flush cycle, or sensor test cycle or that an additive was refilled. Most issues may be addressed quickly.

When all options for managing ballast water on the vessel and in the port were considered and consumed, and no mitigation measure is available, then the minimum amount of ballast water necessary for the vessel to complete the intended operation in the port may be allowed to be discharged. This is clearly against environmental protection principles, hence Parties to the BWM Convention would need to consider providing in the future for some option to manage high or very high risk water in such cases. The Port of Hamburg, e.g., plans to have a reception facility available from 2024 for high-risk ballast water. However, currently, no decision support tool is implemented to identify high-risk ballast water. This reception facility may be implemented as a ballast water reception barge in combination with a land-based reception facility (Oliver Jost, pers. comm.). Furthermore, a new, currently voluntary online service is available to get a ballast water discharge permit for the Port of Hamburg. In accordance with Articles 8, 10, 13 and 18 of the "Gesetz zur Ordnung des Wasserhaushalts" (Federal Water Act) in conjunction with the Hamburg Water Act (Hamburgisches Wassergesetz (HWaG)) and the Port Traffic Regulations (Hafenverkehrsordnung) Artic1e 41 a-c, a permit is required before you may start discharging ballast water. In this online tool,[3] a ballast water discharge permit may be

applied for, and your request is automatically sent to the competent authority. There are specific questions to apply for this permit, including to indicate who you are, vessel's specifics, planned vessel berth in Hamburg, water origin (North Sea, Baltic Sea or outside), whether BWM was conducted to meet the D-l or D-2 standard and the amount of water intended to be discharged.

In conclusion, we believe it is never enough strongly stated how important it is to implement the BWM Convention at the regional scales, and the MoUs are well-established control systems to support the effective implementation of international instruments in the shipping industry. Unfortunately, none by now have adequately considered this. Hence, we would strongly recommend to take this initiative for the sake of the shipping industry and the environmental protection.

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Footnotes

1 As the oldest MoU, established in 1982.

2 Or other duly Authorized Officers.

3 https:serviceportal.hamburg.de/HamburgGateway/Service/Entry/BallastWaE. Last assessed 31.01.2023.

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M. David, S. Gollasch (eds.), *Global Maritime Transport and Ballast Water Management*, Invading Nature - Springer Series in Invasion Ecology 16
https://doi.org/10.1007/978-3-031-48193-2_6

Ballast Water Sampling for Compliance Monitoring and Enforcement of the BWM Convention: D-1 and D-2 Indicative Tests

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Abstract
In accordance with the Ballast Water Management (BWM) Convention, vessels may be subject to inspections for the purpose of revealing violations of convention provisions. To enable this, sampling of ballast water for subsequent analyses is needed. The reliability of compliance tests is of critical importance, since the consequences of failing compliance with the required standards may result in vessels being banned from discharging ballast water, which may result in the inability of completing cargo operations. We tested D-1 and D-2 indicative sampling and analysis methods on commercial vessels during voyages and on vessels calling to Slovenian and Italian ports. Sampling at different depths along the in-tank water column evidenced heterogeneous distribution of physico-chemical parameters, i.e., salinity, temperature, pH and oxygen content, and viable phytoplankton. The highest phytoplankton abundance was observed in bottom samples. Very high phytoplankton abundances of organisms <10 µm were observed compared to organisms 10–50 µm.

Supplementary Information
The online version contains supplementary material available at https://doi.org/10.1007/978-3-031-48193-2_6.

Keywords Ballast water management – Ballast water sampling – Indicative analysis – Abiotic parameters – Viable organisms – BWM Convention compliance monitoring

1 Introduction

The purpose of ballast water sampling studies was so far limited to creating a general scientific interest, awareness raising or the determination of organism numbers per water volume to assess species introduction risks. Each ballast water sampling study objectives triggered the use of different sampling gear and strategies. Furthermore, the high variability in type, size and behaviour of the organisms observed in ballast water samples, combined with the complexity of physical and chemical characteristics of ballast water, implies the use of a variety of sampling methods to recover most of the different viable organisms present in the water (e.g., Medcof 1975; Hallegraeff and Bloch 1991; Gollasch 1996; Ruiz et al. 2000; David et al. 2007).

As the BWM Convention had entered into force in September 2017, IMO Member States will be required to check compliance of vessels with the standards of the BWM Convention, and one way of doing this is sampling ballast water. As per Article 9.1 Inspection of Ships, it is stated that vessels to which the BWM Convention applies may be subject to inspections for the purpose of revealing possible violations of the provisions of the BWM Convention. These inspections shall verify that a valid Ballast Water Management Certificate is carried on board, verify that a Ballast Water Management Plan is on board which is specific to the vessel and is also approved by the Flag State, and undertake a review of the on board Ballast Water Record Book (IMO 2004). As part of the Port State Control efforts to demonstrate compliance with the BWM Convention standards, port authorities may consider sampling of ballast water for subsequent analyses. We here focus on the selection of appropriate sampling methodologies to assess compliance with the BWM

Convention standards, i.e., the ballast water exchange (Regulation D-1) and performance (Regulation D-2) standards. The D-2 standard reads vessels shall discharge (a) less than 10 viable organisms per cubic metre greater than or equal to 50 µm in minimum dimension (predominantly zooplankton); (b) less than 10 viable organisms per millilitre less than 50 µm in minimum dimension and greater than or equal to 10 µm in minimum dimension (predominantly phytoplankton); and (c) toxicogenic *Vibrio cholerae* (O1-O139) with less than 1 CFU (Colony Forming Unit) 100 ml^{-1} of water or 1 g^{-1} (wet weight) of sampled zooplankton, *Escherichia coli* with less than 250 CFU in 100 ml^{-1} and intestinal Enterococci with less than 100 CFU in 100 ml^{-1} (IMO 2004).

During a comparison of sampling methods previously used for ballast water studies, it was observed how different the performance of the individual methods was (Sutton et al. 1998; Gollasch et al. 2003). Furthermore, the patchy distribution of organisms in the tank also impacts the sampling results (Gollasch et al. 2000; Murphy et al. 2002; Taylor et al. 2007; Carney et al. 2013; Gollasch and David 2017). It became clear that sampling methods could over- or under-sample the organisms' abundances. Therefore, by the selection of the wrong sampling method, approach or timing, samples may be wrongly identified as compliant with BWM standards although the organisms' abundance could have been above the compliance threshold, and the opposite.

Noting the sampling bias, it was clear that an international harmonized ballast water compliance control sampling approach was needed. Consequently, the ballast water working group of IMO developed a sampling guideline, i.e., Guidelines for Ballast Water Sampling (G2 Guidelines), adopted in 2008 and additional guidance documents. To overcome this lack of knowledge, IMO

encouraged its member countries to conduct Ballast Water Sampling (BWS) studies and to present the data to IMO. Since MEPC 68 (May 2015), results of sampling studies were made available to IMO and it was concluded that these data need to be presented in a certain format so that the results can be compared. It was further concluded that an Experience Building Phase (EBP) is needed and a correspondence group was initiated to deal with this. The results of the correspondence group were reported to MEPC71 (July 2017) and it was suggested that the EBP may be initiated after the BWM Convention enters into force and that it may last up to five years. In the beginning of EBP, sampling data should be generated and analysed for three years, and this will be followed by a review of BWS guideline and also of the BWM Convention itself (Fig. 1).

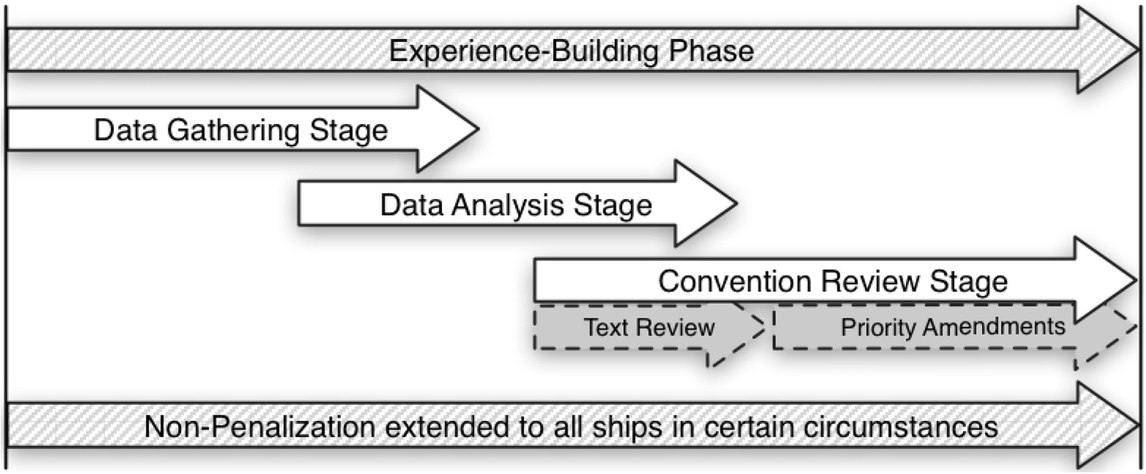

Fig. 1 Stages of the ballast water experience building phase (IMO 2017)

The key objective of the present vessel sampling activity was to document the heterogeneity and possible patterns of biotic and abiotic factors in ballast water when sampling different depths via a sounding pipe or a manhole. This contribution summarizes results of two sampling approaches. In Approach 1, indicative BWS methods were applied on a commercial vessel en route by sampling the

same ballast tank every 12 and/or 24 hours. Samples were analysed using indicative and detailed analysis methods to compare the results and identify the reliability and accuracy of the indicative BWS and analysis (test) methods. In Approach 2, indicative BWS tests were conducted on commercial vessels calling to the Port of Koper in Slovenia and to the Ports of Bari, Ancona, Venice and Trieste in Italy. We identify specifics that port State control (PSC) would need to take into account during conducting inspections as part of the compliance monitoring and enforcement activities of the BWM Convention. For PSC sampling in the ports, it was originally planned also to sample treated ballast water. However, none of the vessels calling to the relevant ports during the study was equipped with a ballast water management system, hence only untreated ballast water was sampled.

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2 Materials and Methods

2.1 D-1 and Indicative D-2 Tests During Vessel Voyages

MD and SG conducted testing of BWS sampling and analysis for compliance monitoring and enforcement (CME) during two vessel voyages in 2015 on the same commercial vessel to document its applicability on board in a real-world scenario. Samples were then further analysed at the Marine Biology Station Piran of the National Institute of Biology (MBS-NIB), Slovenia, within 6–11 days after the sampling event.

The sampling events were carried out on a commercial ca. 21,000 gross tonnage multi-purpose container/bulk carrier during two voyages connecting U.S. ports, i.e., (a) en route from Morehead City, North Carolina to Baltimore, Maryland (voyage 1) and (b) while the vessel was on route

between Corpus Christi, Texas and New Orleans, Louisiana (voyage 2).

All samples were taken from sounding pipes and this was done independently from any ballast water operation of the vessel. Paired tanks number 6 were used (port side and starboard) for the experiment and the identical tanks were used on both voyages. The port side tank had a maximum ballast water capacity of 633.5 m^3 and the starboard side tank 637.3 m^3. For the experiment, the tanks were filled to ca. 90% of their capacity limit. On voyage 1, both tanks were filled on 14 March 2015 in the Port of Morehead City, and on voyage 2, both tanks were filled on 1 August 2015 while the vessel was in the Port of Corpus Christi. On both voyages, the water filled into the portside tank was, while it was pumped on board, treated by a ballast water management system consisting of filtration and UV (tank 1). The starboard side tank was in both tests filled without any water treatment so that this was used as a control experiment (tank 2).

In total, four sampling events were conducted on voyage 1 and six on voyage 2. On voyage 1, samples were taken daily during the four-day voyage. On voyage 2, samples were taken in the evening of Day 1, twice on Day 2 and 3 (morning and evening) and in the morning of Day 4 (Table 1).

Table 1 Timing of sounding pipe sample collection

Voyage	Sample	Day	Date	Time	Location
1	1	1	15 Mar 2015	11:00	Port of Morehead City
	2	2	16 Mar 2015	11:00	Port of Morehead City
	3	3	17 Mar 2015	11:00	At sea, on the way to Baltimore
	4	4	18 Mar 2015	07:00	Port of Baltimore

Voyage	Sample	Day	Date	Time	Location
2	1	1	1 Aug 2015	18:00	Port of Corpus Christi
	2	2	2 Aug 2015	09:00	Port of Corpus Christi
	3	2	2 Aug 2015	19:00	Port of Corpus Christi
	4	3	3 Aug 2015	09:00	On anchor, pilot point for Port of New Orleans
	5	3	3 Aug 2015	19:00	On anchor, pilot point for Port of New Orleans
	6	4	4 Aug 2015	09:00	On anchor, pilot point for Port of New Orleans

Samples were taken from three positions: at the water top in the sounding pipe, the middle of the water column and from the bottom. Sampling was enabled by using a small point source sampler developed by MD for PSC purposes with a metered rope so that it could be lowered in the sounding pipe to the required depth (see Fig. 2). The sampler’s water volume capacity is ca. 45 ml. To reach the target sample water volume of ca. 90 ml, which was needed to allow the application of all sample analysis methods (see below), the sampler was employed multiple times to the same depth, and a water bottle was filled on deck at the sampling point for each sampling depth separately. The sample volume, which remained after sample processing on board, was kept in the original sample bottle and stored in a Styrofoam box with a cooling element for subsequent analysis of phytoplankton in a land-based laboratory (see below).

Fig. 2 The David's (small spot) sampler for PSC use

On all sampling events, the tank filled with the treated water was sampled first. This approach was chosen to avoid any possible "contamination" of living organisms moved with the sampling gear or sample processing material used for the organism-richer control tank water with the water in the treated tank.

Temperature and salinity in each sample were measured directly after sampling at the sampling point by using a WTW conductivity meter (Weilheim, Germany).

The phytoplankton was analysed on board by the bbe 10 cells pulse amplitude modulated fluorometer (PAM)

manufactured by bbe (Moldaenke, Schwentinental, Germany). In general, PAM instruments analyse the photochemical efficiency of the photosystem II in phytoplankton, and the result is an indicator of the viability condition of the phytoplankton in the sample. Other than traditional PAMs, this PAM converts its algae activity measurement into cell numbers, and this calculation is based upon tests with a reference algae. For each sample, three replicate measurements were done by filtering 10 ml of sample through an 8 µm filter. Prior to filtration, the sample was mixed by stirring. The filter was dried from excess water with a paper towel from the bottom to avoid water spillage into PAM. Thereafter, the filter was inserted in PAM for measurement. This PAM converts the phytoplankton viability signal into a cell abundance, and this conversion is based upon a reference algae (Moldaenke pers. comm.; Gollasch et al. 2015).

After return to Europe, the samples were processed at the MBS-NIB laboratory and samples from all depths were mixed and processed as one sample. Here, epifluorescence microscopy was applied with fluorescein diacetate (FDA) stained samples to count living organisms (≥10 and <50 µm size class in minimum dimension) in all samples following Adams et al. (2014). After staining with FDA, the samples were incubated in the dark for 10 minutes. The sample was then mixed and 1 ml was transferred into a Sedgewick-Rafter chamber and examined at 100× magnification under the Zeiss epifluorescence microscope, model AxioObserver Z1 by using the filter set 09 (i.e., excitation at 450–490 nm, emission at >515 nm). FDA stains only phytoplankton cells with an intact cell membrane which show metabolic activity producing intracellular esterases fluorescently green. These cells were classified as living and counted (Garvey et al. 2007; Gollasch et al. 2015).

For all samples, half of the Sedgewick-Rafter chamber was investigated for stained algae, and this was done in duplicate. Stained single cells and individual cells of colonial and filamentous structures were counted. The counting time per single Sedgewick-Rafter chamber was approximately 20 min.

2.2 D-1 and Indicative D-2 Tests on Vessels in Adriatic Ports

Ballast water sampling was conducted in four Italian ports (Bari, Trieste, Venice and Ancona) and in one Slovenian port (Koper) between April 2015 and February 2016. In each port, 10 ships' ballast tanks were sampled with the "*in-tank*" method according to available access point (manholes or sounding pipes), as proposed in the "BALMAS Ballast Water Sampling Protocol for Compliance Monitoring and Enforcement of the BWM Convention and Scientific Purposes" (David and Gollasch 2014). The tanks to be sampled were identified by the chief, considering the availability of sampling access points. The tank selection was also influenced by holding time and ballast water origin.

In the port of Koper, tanks to be sampled were selected based on shorter in-tank holding time from the targeted donor port. Ballast water samples were taken via sounding pipes from different depths in the same way as described here in Sect. 2.1. In Italian ports, ballast water was sampled mostly via tank openings (manholes). Furthermore, an integrated sample was taken from a sounding pipe with a hand pump. During pumping out 100 litres of sample, the suction side of the hose was slowly lowered down the sounding pipe, and discrete samples were taken with a cup throughout the entire pumping time. One cup of approximately 2 decilitres was filled every 10 litres of ballast water being pumped out so that in total an

integrated 2 litre sample was collected for phytoplankton analysis.

In the Port of Koper sampling campaign, an on-spot phytoplankton viability analysis was conducted with the bbe 10 cells and Ballast-Check 2 (BC, Turner Designs, San Jose, USA), salinity, temperature and oxygen were measured with a handheld multiparameter probe (model Multi 350i, WTW, Germany). pH was measured according to the method described in Grasshoff et al. (1999) using a Metrohm 744 pH meter (Herisau, Switzerland). BC has a measurement maximum range of 2000 phytoplankton cells/mL and a detection limit sensitivity of less than 10 cells/mL. The fluorescence response from the algae is converted into algal cell abundance so that the set fluorescence thresholds in Ballast-Check 2 define values for the abundance and activity (ratio between Fv/Fm) of algae in the ballast water sample. Samples with “High risk” will report an abundance greater than 10 cells/mL and an activity greater than 0.25. If the Abundance is less than 10 or the activity is less than 0.25, then the risk assessment will display a “Low risk”. In the Italian sampling campaign, temperature and salinity (D-1-standard test) were measured using a handheld conductivity meter (HQ14d, Hach, Loveland, USA) or a thermocouple thermometer (HANNA HI935005, Woonsocket, USA) and a handheld refractometer (ATAGO S-10E, Tokyo, Japan). For the D-2 indicative test, the active Chlorophyll a was measured using a handheld fluorometer (BW680 Ballast Water Fluorometer, Hach Inc., Loveland, CO, USA). This instrument indicated a “high risk” if active, the Chl a value was higher than 0.16 µg l^{-1}, or a “low risk”, if Chl a value was below this limit. For the detailed D-2 compliance test, the phytoplankton was analysed in laboratories as described in Sect. 2.1 (Figs. 3 and 4).

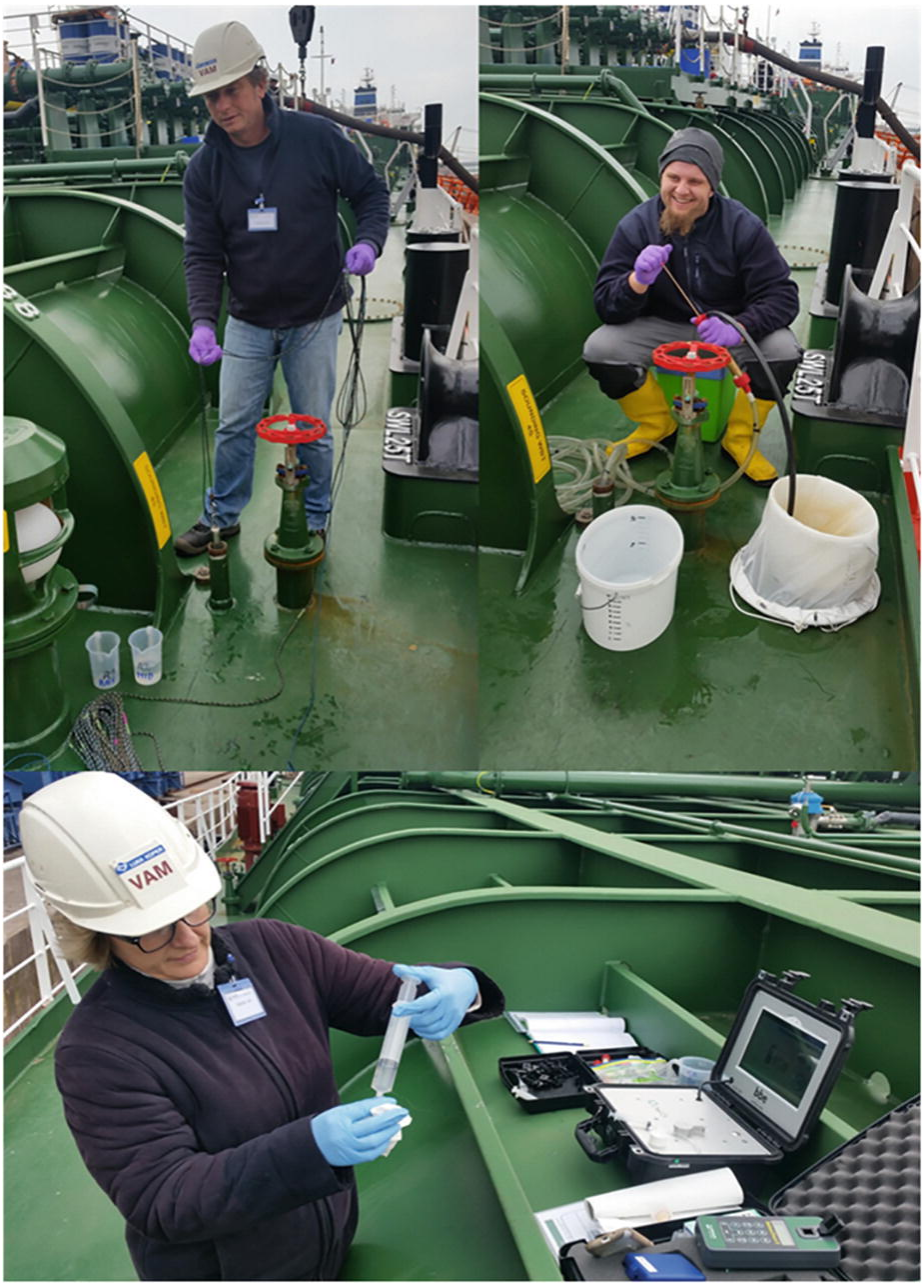

Fig. 3 Sampling and analysis setup on a vessel in the Port of Koper. Top left—deployment of David's sampler for PSC, top right—sampling with the hand pump, and bottom—on-spot measurements with bbe 10 cells and Ballast-Check 2 PAM instruments

Fig. 4 Sampling with the David's sampler operated through manhole (top left) and via a sounding pipe (top right), operating a plankton net via a manhole (bottom left), measuring phytoplankton viability with Hach PAM fluorimeter (bottom centre), measuring salinity with a handheld refractometer (bottom right), on a vessel in the Port of Trieste

3 Results

3.1 CME Methods Tests During Vessel Voyages

As described in the following chapters, the heterogeneity of phytoplankton inside the sounding pipe and ballast water stratification was clearly documented on both voyages.

3.1.1 D-1 Salinity Test

The salinity was in most cases different in the different sounding pipe depths during voyage 1. Only in one sampling event, all samples had the same salinity. In three cases, the salinity at the bottom was higher than at the top, and in two cases, the reverse was found. The maximum difference between top and bottom salinity was 1.2 psu. During voyage 2, the salinity was in all cases different in the different sounding pipe depths. With one exception, the salinity at the bottom was always higher than at the top. The maximum difference between top and bottom salinity was 1.5 psu, even a bit higher than during voyage 1 (see Supplement 1).

Figure 5 shows the mean salinity value over all measurements of both voyages. The salinity is highest at the tank bottom compared to the middle and top sounding pipe samples. The top and middle salinity values are with a difference of less than 0.1 psu much closer compared to the distance between middle and bottom salinity, which is slightly greater than 0.5 psu.

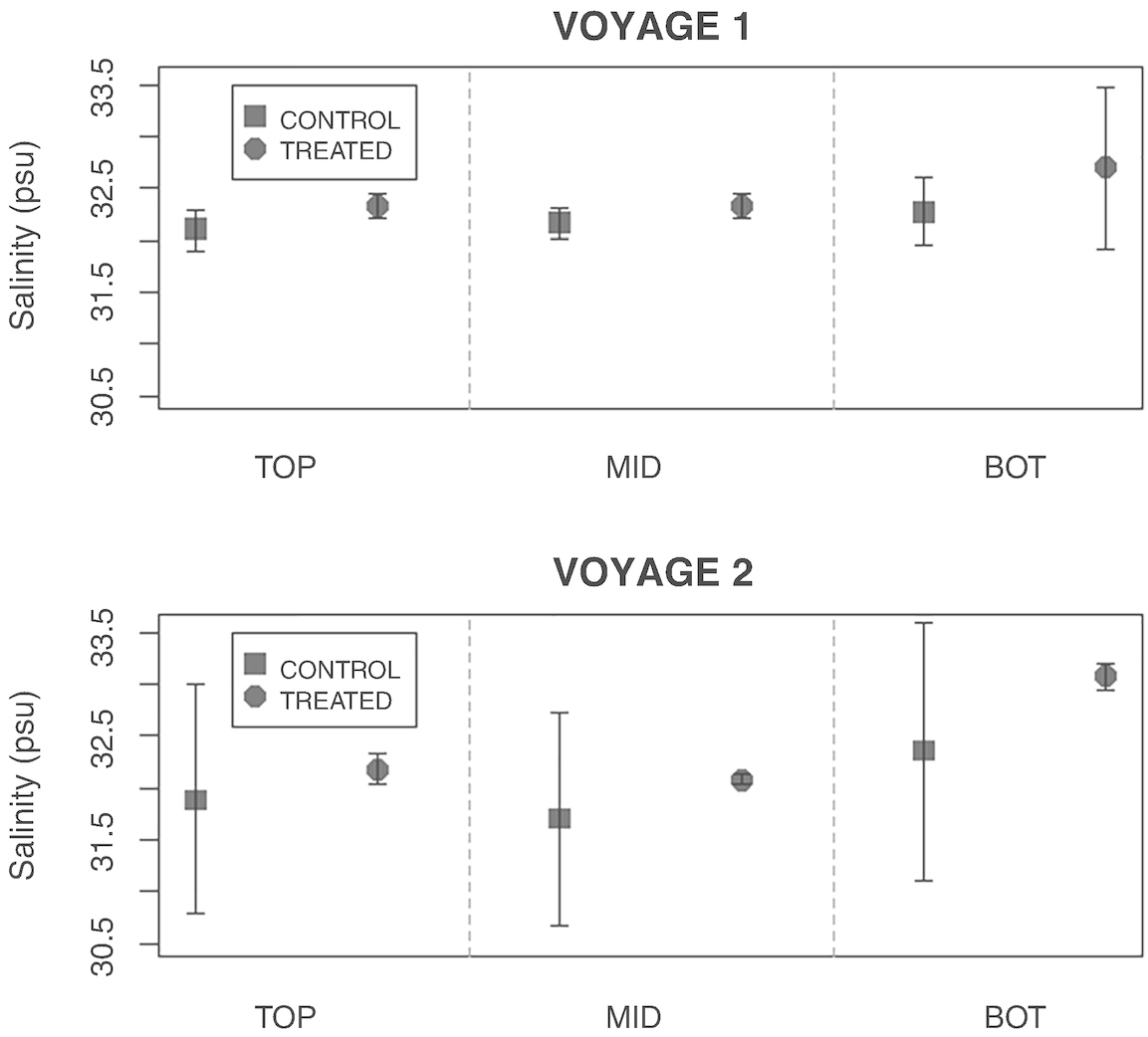

Fig. 5 Mean salinity (± SD) of samples taken at the top (TOP), middle (MID) and bottom (BOT) of the treated and control ballast water tanks during both voyages. *N* (voyage 1) = 3, *N* (voyage 2) = 6

3.1.2 D-2 Indicative Tests

During voyage 1, in most cases, the highest phytoplankton abundance was measured by the bbe in the bottom samples. When comparing the bbe and microscope counts, it becomes clear that the microscope counts are, with one exception, always lower than the bbe counts and some differences are substantial. A comparison of the phytoplankton abundance between the two test tanks clearly shows a much lower abundance in tank 1, which contained the treated water. It is also interesting to note

that the phytoplankton abundance in tank 1 with treated water decreased from day 1 to day 2 and thereafter remained at a level between 50 and 55 cells/ml. In contrast, the phytoplankton abundance increased in tank 2 with the untreated control water. In the same way as during voyage 1, during voyage 2, with one exception, the highest phytoplankton abundance was measured by the bbe in the bottom sample. When comparing the bbe and microscope counts, it becomes clear that the microscope counts are in most cases lower than the bbe results, but in four cases, the microscope counts were higher than the bbe results. As observed on voyage 1, the phytoplankton abundance in tank 1 (treated water) was much lower compared to tank 2 (untreated water). Here, the phytoplankton abundance in both tanks decreased over time (see Supplement 1).

Considering the mean phytoplankton cell number over all samples, the highest abundance was found in the bottom samples with a difference of approximately 150 cells/ml compared to the top samples. It is interesting to note that the mean value of the top, middle and bottom measurements shows a very similar cell count to those measured in both the middle sounding pipe samples and in the mixed samples (Fig. 6).

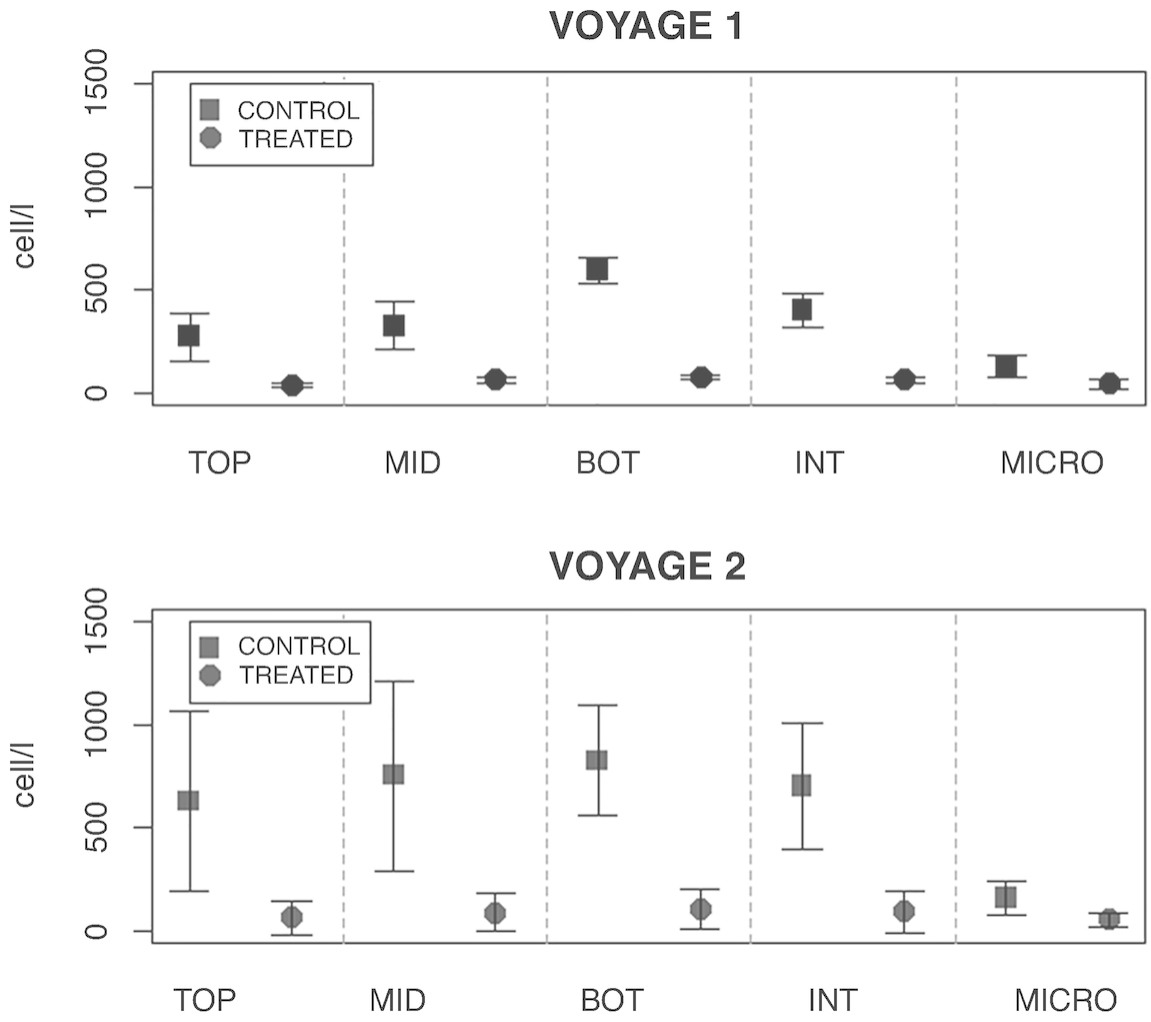

Fig. 6 Mean number (± SD) of viable organisms in the size range ≥10 and <50 µm in minimum dimension measured with bbe 10 cells at the top (TOP), middle (MID) and bottom (BOT) of the sounding pipe, and in the integrated sample (INT) of the three aforementioned depths during both voyages. MICRO: microscope counts of the integrated samples. Results of the control and treated ballast water tanks are presented separately. *N* (voyage 1) = 4, *N* (voyage 2) = 6

3.1.3 Phytoplankton Below 10 µm

The microscope counts of the viable phytoplankton cells below 10 µm were documented for voyage 1 only. Here, the cell abundance fluctuated between 1000 and 7000 cells/ml and was much higher, in several cases by one order of magnitude, than the counts for the ≥10 and <50 µm cells. In tank 1 (treated water), the values oscillated without a

clear trend between 1000 and 2460 cells/ml during the voyage. A similar situation was observed for tank 2 (control water), but with a phytoplankton abundance being between more than double and 4 times higher than the tank 1 abundances (see Supplement 1 and Fig. 7).

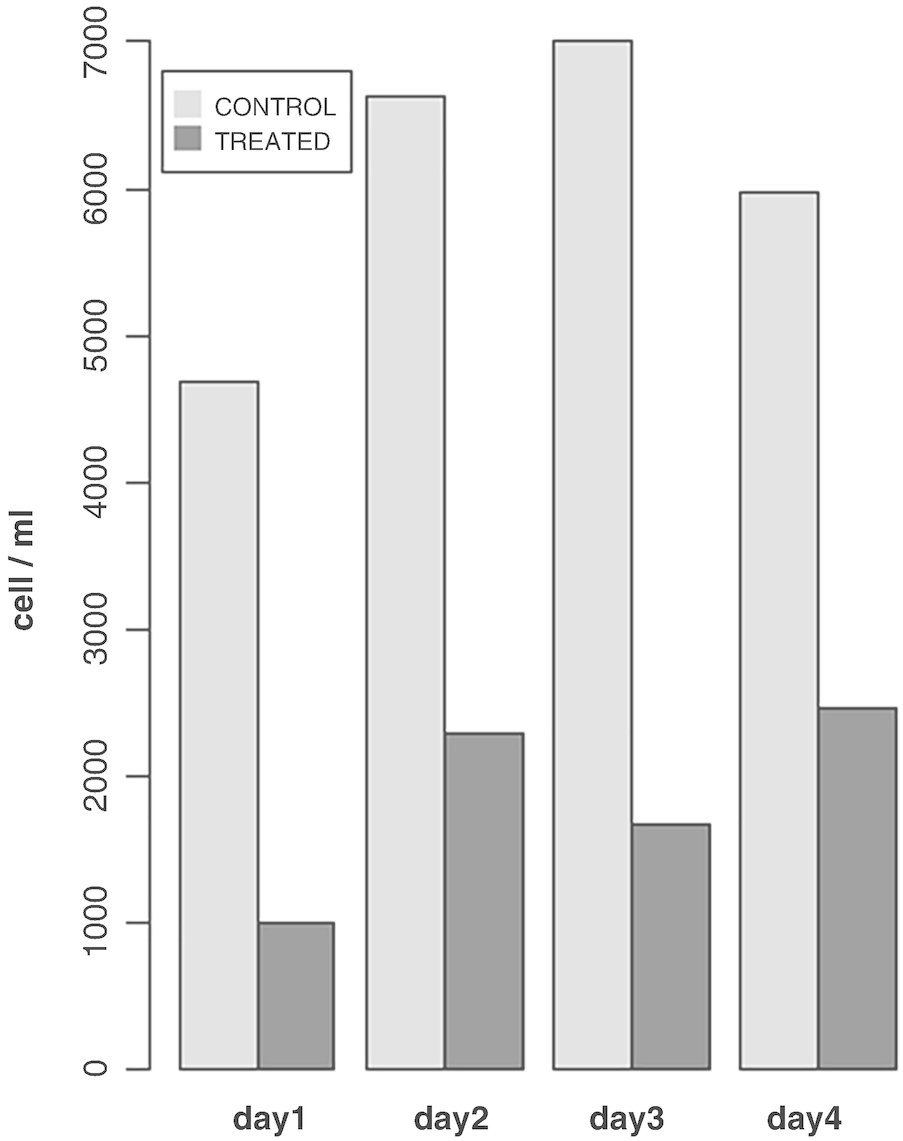

Fig. 7 Number of viable organisms in <10 µm in minimum dimension counted with the microscope in the mixed samples from the top, middle and bottom of the ballast water tank from voyage 1

3.1.4 Temperature Measurements

During voyage 1, in all sampling events, the temperature at the bottom was lower than at the top, with a maximum of 2 °C difference. Over voyage 2, a substantial temperature drop was recorded during day 4 (last day). During most sampling events, the temperature at the bottom was lower than at the top, with a maximum of 1.3 °C difference, i.e., slightly less than during voyage 1 (see Supplement 1).

The mean values of all temperature measurements showed that the highest temperature was measured at the top of the sounding pipe, which was ca. 0.6 °C warmer compared to the middle sounding pipe samples. The temperature difference between the middle and the bottom water samples was less than 0.2 °C. The lowest temperature was measured at the bottom samples (Fig. 8).

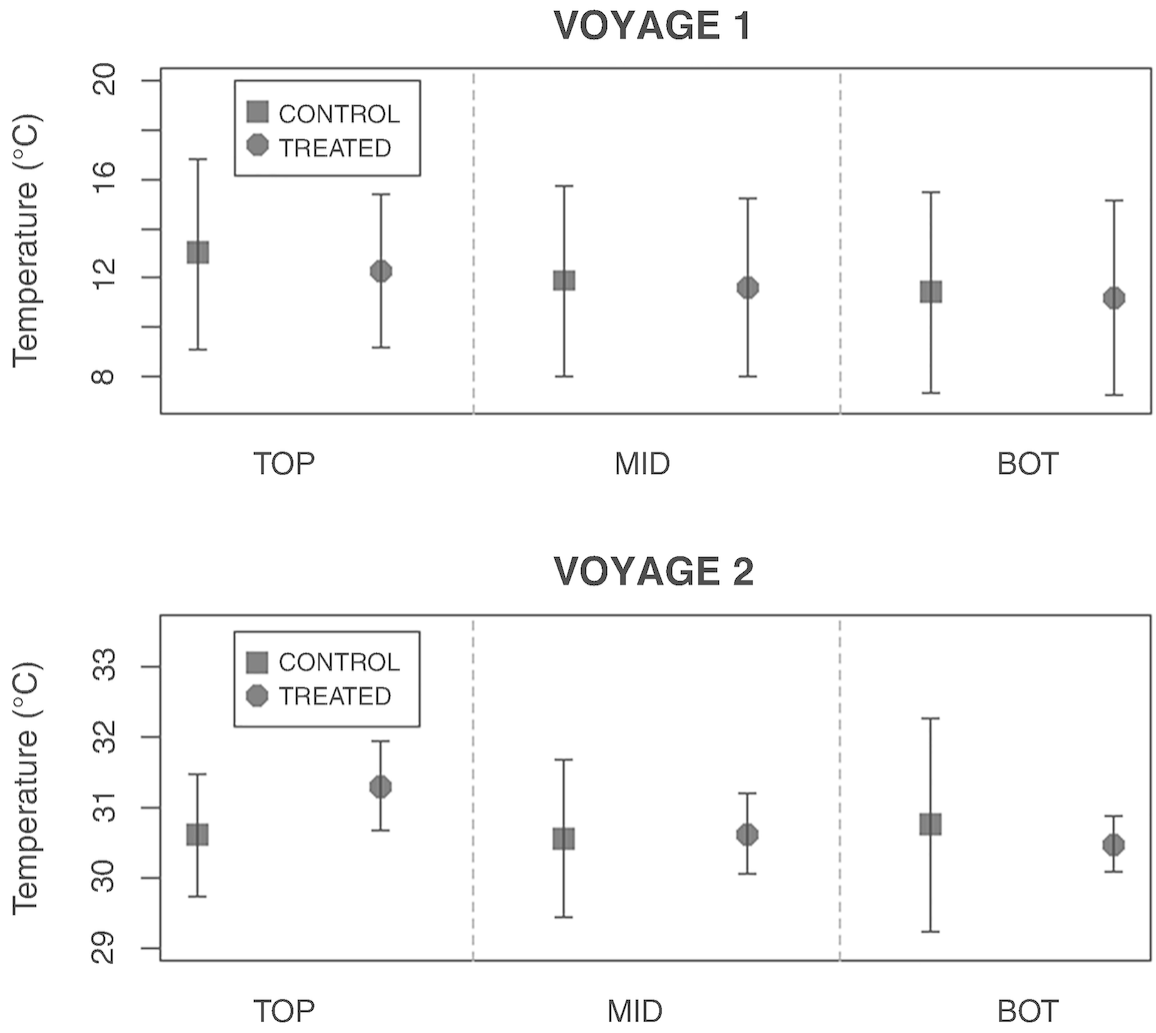

Fig. 8 Mean temperature (± SD) of samples taken at the top (TOP), middle (MID) and bottom (BOT) of the treated and control ballast water tanks during both voyages. Note the different scales on the *y*-axes. *N* (voyage 1) = 3, *N* (voyage 2) = 6

3.2 CME Methods Tests in Adriatic Ports

3.2.1 The Port of Koper Sampling Results

3.2.1.1 D-1 Salinity Tests

The salinity ranged between 34.2 and 38.5 psu. The mean salinity values of all ten vessels sampled in the Port of Koper are shown in Fig. 9. The highest salinities were, in most cases, determined in samples taken at the bottom of the sounding pipe. The middle and bottom samples had a similar salinity value, but the top values were more than

1 psu value lower. Considering the individual vessels, the measurements in vessel V1 showed with 6.1 psu the greatest difference between the top and bottom samples. Three vessels showed a salinity difference of only 0.1 psu between top, middle and bottom measurements and in vessel V4 all salinity values were identical (see Supplement 2 and Fig. 9).

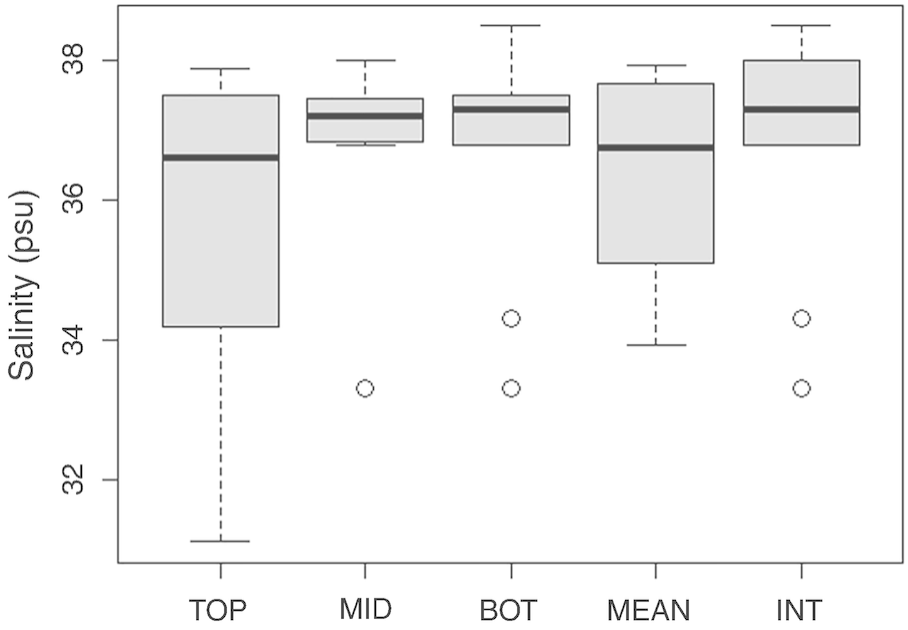

Fig. 9 Water salinity of samples taken at the top (TOP), middle (MID) and bottom (BOT) of the ballast water tanks and of the integrated sample (INT). MEAN is the calculated average of the three discrete sampling depths. Samples were taken on vessels (N = 10) arriving in the Port of Koper. Open circles denote outliers

3.2.1.2 D-2 Indicative Tests

Indicative phytoplankton measurements were conducted on the spot on board of the vessels and then compared to microscope counts of viable organisms ≥10 and <50 µm in minimum dimension. The abundance of viable organisms ≥10 and <50 µm in minimum dimension in different ballast water samples was quite variable. The microscope counts ranged from 1 to 29 cells/ml with an average for all samples of 6.7 cells/ml (see Supplement 2). Regarding the

different depths of the ballast water tank, the lowest values were observed in the upper part of the water column in the tank, while the highest abundances were counted in the middle part of the tank. In comparison, the integrated ballast water sample did not reflect an average of all three depth segments but instead showed values similar to the upper part, which showed the lowest viable organisms abundances (see Supplement 2).

When comparing the mean numbers of viable phytoplankton cells in the size range ≥10 and <50 µm measured with different instruments, it was observed that the mean bbe 10 cells values in all samples were much higher compared to BC and microscope counts. BC and microscope counts were of similar values in the middle, mean and especially the bottom samples. In the top samples, the microscope count was less than half of BC count. The integrated sample, which was only processed by the microscope, showed similar viable cell abundances as the sample taken from the top of the sounding pipe (Fig. 10).

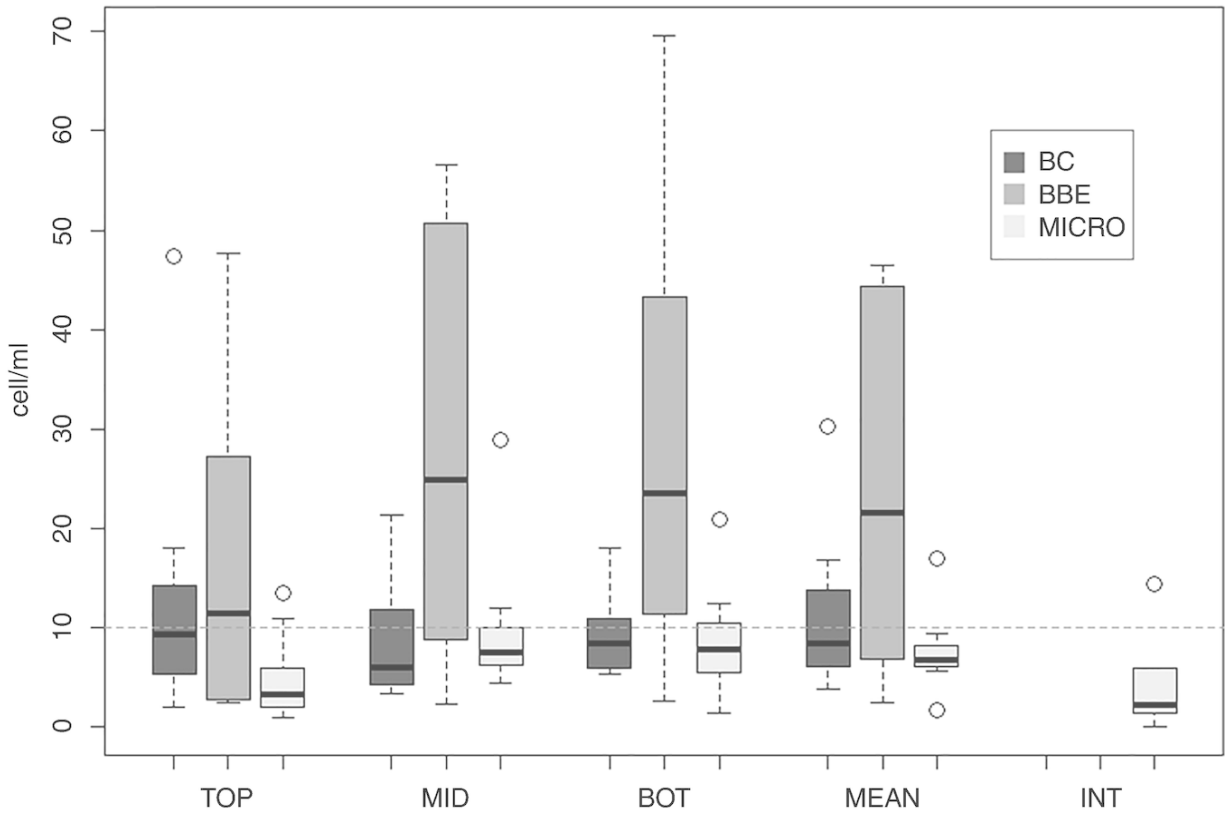

Fig. 10 Counts of viable phytoplankton in the size range ≥10 and <50 µm in minimum dimension collected at the top (TOP), middle (MID) and bottom (BOT) of the ballast water tanks of vessels (N = 10) arriving in the Port of Koper. MEAN is the calculated average, while INT is the integrated water sample count of the three sampling depths. Viable phytoplankton was detected using the Ballast Check II (BC) and bbe 10 cells (bbe) instruments and by counting fluorescent cells under the microscope (MICRO). Dashed line at 10 cells/ml represents the distinction between compliance and non-compliance with the D-2 standard. Open circles denote outliers

3.2.1.3 Phytoplankton Below 10 µm and Above 50 µm

The abundance of viable phytoplankton organisms <10 µm was very variable, though much higher than the abundance of organisms ≥10 and <50 µm in minimum dimension in all levels of the ballast tank's water column, and ranged from 73 to 3321 cells/ml (see Table 2 and Supplement 2).

Table 2 Information about vessel type, donor port or area and days in tanks

Port	Vessel number	Vessel type	Ballast water donor port or area	Days in tank
Port of Koper	V1	Container	Haifa	4
	V2	General cargo	Misurata	5
	V3	General cargo	Bejaia	7
	V4	Bulk carrier	Chioggia	4
	V5	Bulk carrier	Marghera	2
	V6	Bulk carrier	Ravenna	2
	V7	Chemical tanker	Ravenna	6
	V8	General cargo	Rijeka	6
	V9	General cargo	Split	6
	V10	Container	Piraeus	10
Port of Trieste	V11	Oil tanker	Black Sea	NA
	V12	Ro ro	Middle Adriatic	1
	V13	Ro ro	Ionian Sea	16
	V14	Ro ro	Southern Adriatic	5
	V15	Ro ro	Ionian Sea	1
	V16	Ro ro	Ionian Sea	12
	V17	Ro ro	Ionian Sea	28
	V18	Ro ro	Ionian Sea	20
	V19	Ro ro	Ionian Sea	1
	V20	Ro ro	Ionian Sea	26

Port	Vessel number	Vessel type	Ballast water donor port or area	Days in tank
Port of Venice	V21	Container ship	Cyclades	14
	V22	Container	Eastern Mediterranean	11
	V23	Container	Venice	1
	V24	Container	Venice	1
	V25	Container	Piraeus	2
	V26	Container	Rijeka	NA
	V27	Container	Trieste	2
	V28	Container	Piraeus	2
	V29	Container	Piraeus	65
	V30	Container	Venice	36
Port of Ancona	V31	Container	Misurata	6
	V32	Passenger	Patrasso	1
	V33	Container	Trieste	76
	V34	General cargo	Atlantic Ocean	29
	V35	Passenger	Ancona	NA
	V36	Passenger	Split	1
	V37	Passenger	Ancona	NA
	V38	Passenger	Ancona	NA
	V39	Container	Venice	NA
	V40	Passenger	Ionian Sea	NA

Port	Vessel number	Vessel type	Ballast water donor port or area	Days in tank
Port of Bari	V41	Container	Gioia Tauro	7
	V42	Bulk carrier	Durres	3
	V43	Container	Piraeus	50
	V44	Bulk carrier	Atlantic Ocean	8
	V45	Container	Gioia Tauro	8
	V46	Bulk carrier	Durres	2
	V47	Container	Crete	42
	V48	Container	Bari	18
	V49	Bulk carrier	Ravenna	12
	V50	Bulk carrier	Swansea	20

The mean abundance was the highest in the middle water column, while the lowest average was in the top part. As with ≥10 and <50 µm organisms, the integrated ballast water sample has the lowest number of viable organisms (see Supplement 2 and Fig. 11).

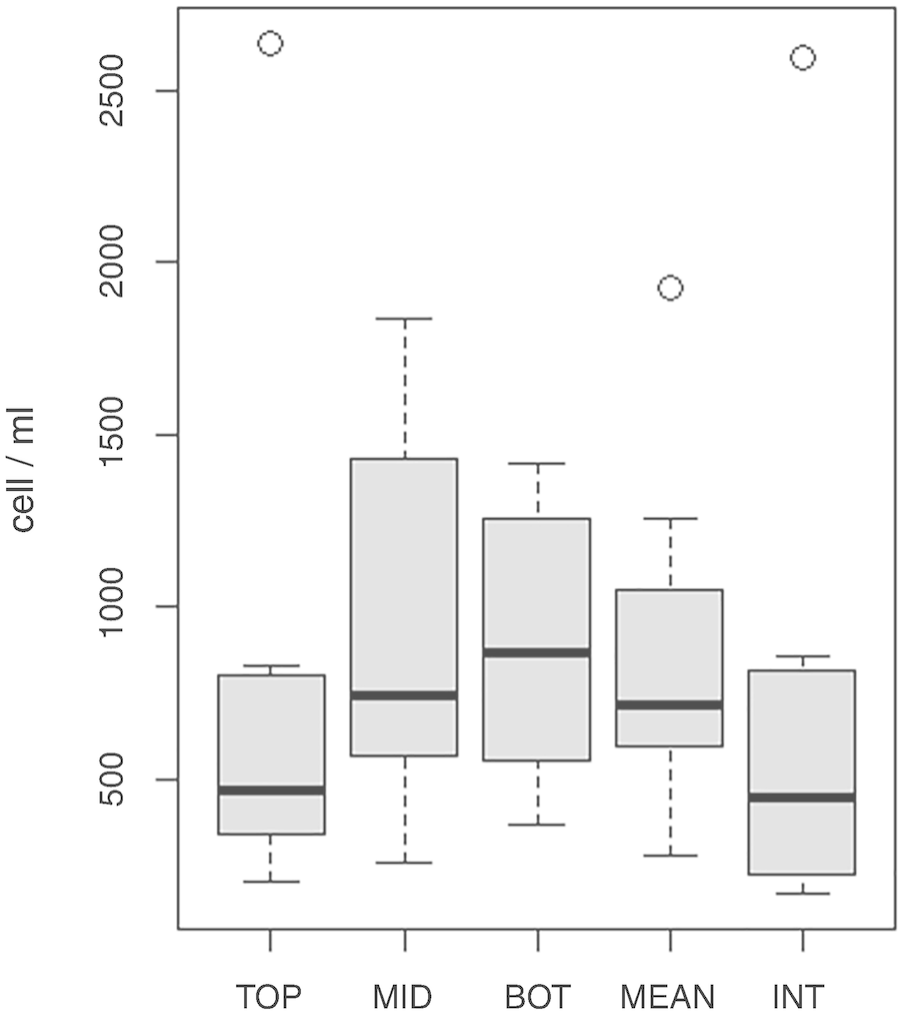

Fig. 11 Mean number of viable phytoplankton organisms in <10 µm in minimum dimension counted with the microscope in the mixed sample from the top (TOP), middle (MID) and bottom (BOT) of the ballast water tanks of vessels (N = 10) arriving in the Port of Koper. MEAN is the calculated average, while INT is the integrated water sample count of the three sampling depths

Viable phytoplankton organisms >50 µm were found only in three samples, i.e., top sample of vessel 6 and the middle and bottom samples of vessel 9, all findings were in abundance below 1 cell/ml (see Supplement 2).

3.2.1.4 Temperature, Oxygen and pH Measurements

The temperature ranged from 10.0 to 15.5 °C in all samples from all vessels. The highest temperature difference between the three sampling depths in one vessel was 2.7 °C (vessel V1) and the lowest 0.3 °C (vessel V4). During

most sampling events, the highest temperature was measured in the bottom samples (see Supplement 2). When considering the mean values over all sampled vessels in the Port of Koper, the highest temperature difference between the top, middle and bottom samples is approximately 0.1 °C, and the calculated mean value is very similar to the temperature measured in the top sounding pipe sample. The mean integrated samples were ca. 0.5 °C warmer than the sounding pipe bottom samples (see Fig. 12).

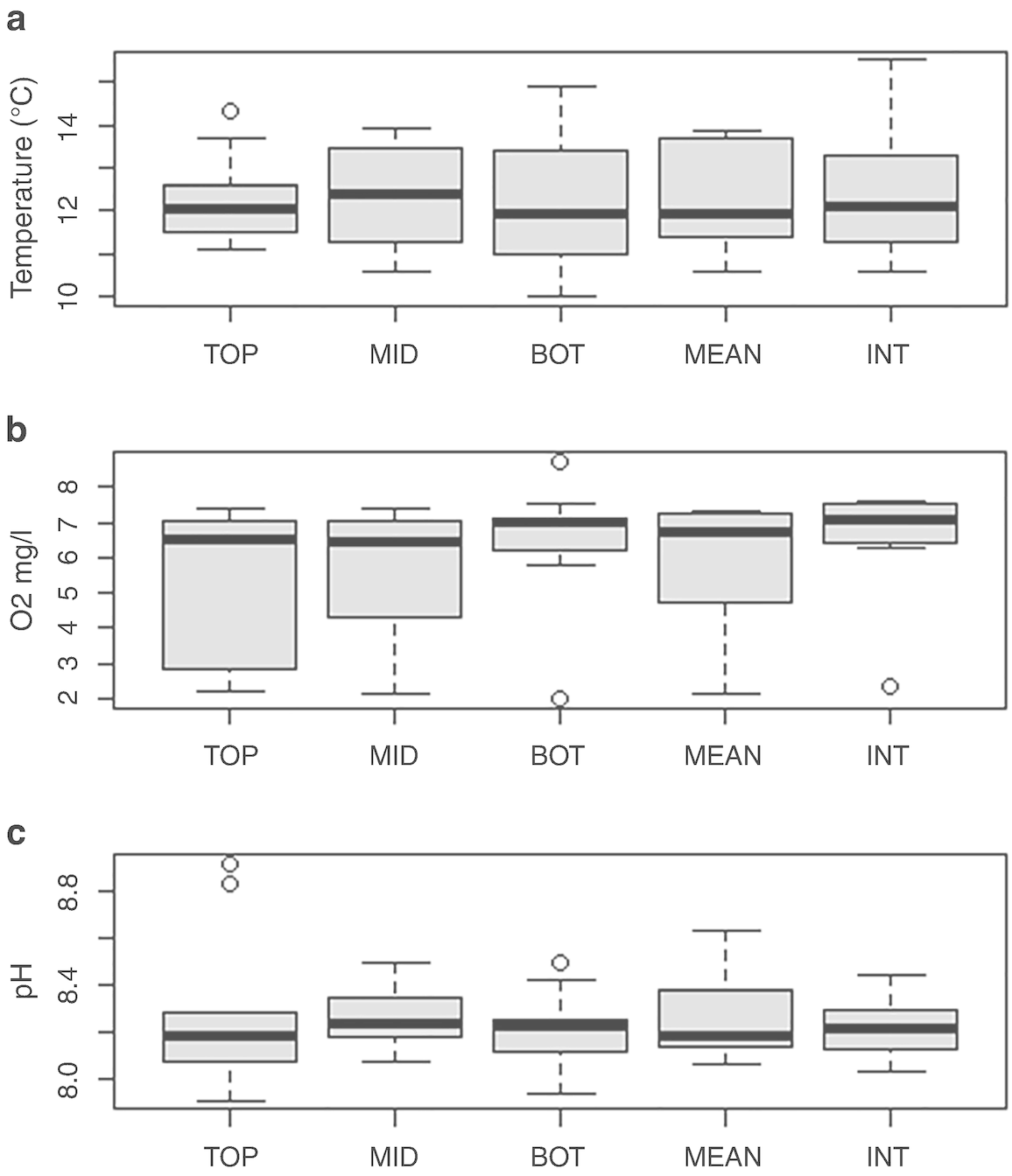

Fig. 12 Boxplots of (**a**) temperature, (**b**) dissolved oxygen and (**c**) pH of water samples collected at the top (TOP), middle (MID) and bottom (BOT) of the ballast water tanks and of the integrated sample (INT). MEAN is the calculated average of the three discrete sampling depths. Samples were taken on vessels (N = 10) arriving in the Port of Koper. Open circles denote outliers

The oxygen level in the sounding pipe samples fluctuated between 2.01 and 8.71 mg/l. The highest difference during one sampling event occurred for vessel

V3 with a difference of 3.35 mg/l between top and bottom samples, where the top sample measurement was 2.86 mg/l and the bottom measurement was 6.21 mg/l. In contrast, in vessel V7, the oxygen level was very similar in all samples, ranging from 6.65 mg/l at the top to 6.67 mg/l at the bottom. In general, the highest oxygen concentrations were measured in the bottom samples. The mean value of the top, middle and bottom sounding pipe samples was similar to the mean values measured in the middle of the sounding pipe. The integrated sample value was similar to the mean bottom samples (see Supplement 2 and Fig. 12).

The pH values ranged between 7.91 and 8.92 in all samples from all vessels. The greatest difference occurred in vessel V10 with 0.61. The smallest difference observed between samples was < 0.1 (see Supplement 2). Figure 12 shows that the mean pH value was lowest in the mean bottom samples, followed by top and middle samples. The integrated sample values were below the mean value of the top, middle and bottom samples.

3.2.2 Italian Ports Sampling Results

3.2.2.1 Port of Bari

Ballast water samples were taken from ten commercial ships which arrived in the Port of Bari between July and September 2015, with ballast water originating mostly from the Mediterranean basin. Only two ballast water origins were from outside the Mediterranean. All vessels followed their ballast water management plans, but no vessel had a ballast water management system on board. The holding time of ballast water in the tank prior to sampling varied between 2 and 50 days (see Table 2). The temperature ranged from a minimum of 19.5 °C (V44 bottom sample) to a maximum of 29.8 °C (V50 middle sample). The mean value for samples at the top was 24.2 °C, 24.4 °C at the middle and 23.2 °C at the bottom of the sampled tanks. The

salinity values ranged from a minimum of 0.0 psu (at the top of V44) to a maximum of 41.0 psu (at the bottom of V47) with a mean top value of 31.6 psu, 34.1 psu at the middle and 35.7 psu at the bottom of the sampled tanks. The highest salinity difference in a single tank was measured on V44, where the top sample had 0.0 psu and the middle and bottom samples had salinities of 32.0 and 37.0 psu. The ballast water sample from vessel 48, for which only a top-level measurement was taken, was at low risk after the indicative test and resulted slightly above the limit (i.e., 10 viable cells/ml). The ballast water sample from vessel 50, that was at low risk by indicative PAM fluorometry, resulted very near the limit at the microscopic analysis (i.e., 9 viable cells/ml) (see Supplement 3).

3.2.2.2 Port of Ancona

The ballast water sampling programme in the port of Ancona was performed in September 2015. In total, ten tanks were sampled with ballast water originating mostly from the Mediterranean basin and one from the Atlantic Ocean. The holding time of ballast water in the tank prior to sampling varied between 1 and 76 days (see Table 2), but for half of the vessels holding time data were unavailable. The temperature ranged from a minimum of 23.9 °C (V32 middle and bottom samples) to a maximum of 26.4 °C (V40 top sample). The mean value at the top was 25.4 °C, 25.0 °C at the middle and 24.8 °C at the bottom of the sampled tanks. The salinity values ranged from a minimum of 10.2 psu (V34) to a maximum of 38.0 psu (at the bottom of V40) with a mean value of 33.7 psu at the top, 34.0 psu at the middle and 33.9 psu at the bottom of the sampled tanks. Viable plankton organisms in the range ≥10 and <50 µm were found in all ballast water tanks sampled in the Port of Ancona and the abundances of the viable cells mostly exceeded the IMO limits. In the detailed analysis, viable plankton organisms were found in all

ballast water sampled in the Port of Ancona and in most cases the D-2 standard was exceeded. Only ballast water originating from Trieste (V33), the Atlantic Ocean (V34) and Ancona (V37) were in compliance with IMO standards (see Supplement 3).

3.2.2.3 Port of Venice

The ballast water sampling programme in the port of Venice was performed from July to September 2015. The ten sampled tanks contained ballast water originating mostly from the North Adriatic basin, Aegean Sea and other Mediterranean regions. The holding time of ballast water in the tanks prior to sampling varied between 1 and 65 days (see Table 2). The temperature ranged from a minimum of 24.1 °C (V27) to a maximum of 30.5 °C (at the bottom of V24); generally, among the three sampling points in each tank, the temperature was rather homogeneous. Salinity values ranged from a minimum of 32.2 psu (V23 at the top) to a maximum of 39.0 psu (V22 at the top and bottom). Averaged values varied from 32.3 psu (V23) to 39.0 psu (V22). Concerning the photosynthetic activity, half of the ten sampled ballast tanks (V22, V25, V26, V28 and V29) showed low risk, as measured by indicative PAM fluorometry, along the whole water column sampled. Viable plankton organisms were found in all sampled tanks in the Port of Venice, as revealed by microscope counts. The abundance of viable cells mostly exceeded the D-2 standard; only three samples, one with ballast water originating from Rjieka (V26) and two from Pyreus (V28 and V29), were in compliance with IMO standard (see Supplement 3).

3.2.2.4 Port of Trieste

The ballast water sampling programme in the Port of Trieste was performed from April to June 2015. Among the ten ballast water tanks sampled on commercial vessels,

only one (V11) contained water originating from outside the Mediterranean Sea, while the other vessels carried water from the middle and southern Adriatic and Ionian Seas. The holding time of ballast water in the tanks prior to sampling varied between 1 and 28 days (see Table 2). The temperature ranged from a minimum of 15.8 °C (V11 at the bottom) to a maximum of 27.1 °C (V19 at the top) with a mean value of 24.0 °C at the top, 23.1 °C at the middle and 22.4 °C at the bottom of the sampled tanks (see Table 2). The salinity values ranged from a minimum of 17.4 psu (V11 at the top) to a maximum of 38.0 psu (V18 at the top) with a mean value of 34.9 psu at the top, 35.3 psu at the middle and 36.8 psu at the bottom of the sampled tanks. It is interesting to note that in V11 the top salinity (17.4 psu) is almost half of the salinity value in the bottom water sample (31.7 psu). This is the strongest salinity difference within one tank of all the tanks sampled. In five ballast water tanks, low risk was identified by indicative PAM fluorometry along the whole water column; three tanks were characterized by high risk values (V12, V13 and V15). Risk indication inconsistencies were observed in two tanks where the risk level changed according to the sampling depth (V11 and V19). In V11, a high risk was indicated only along the bottom layer, while the middle and top samples showed low risk. In V19, the opposite situation was observed with low risk at the bottom and high risk at the middle and top. Viable organisms were found in all ballast water samples taken on vessels in the Port of Trieste. The abundance of viable cells exceeded the D-2 limits in all samples (see Supplement 3).

3.2.2.5 Summary of Italian Ports Results

The distribution of mean salinity values showed a vertical stratification. The mean salinities of all 40 samples taken on vessels in Italian ports showed clearly that the bottom sounding pipe samples were of the highest salinities.

However, the mean difference between the lowest salinity (top samples) and highest salinity (bottom samples) was below 1 psu (see Fig. 13).

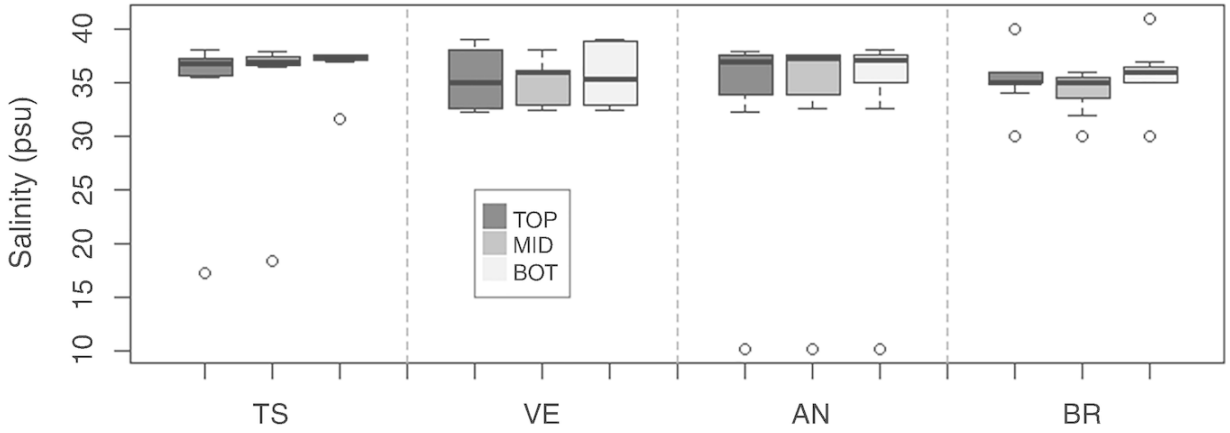

Fig. 13 Salinity of the water samples collected at the top (TOP), middle (MID) and bottom (BOT) of the ballast water tanks. Samples were taken on vessels arriving in the ports of Trieste (TS), Venice (VE), Ancona (AN) and Bari (BR). In all ports, $N = 10$. Open circles denote outliers

The photosynthetic activity (which is considered as an indicator of viable cells) resulted in several samples in different risk categories according to the sampling depth, thereby revealing a non-homogeneous organism stratification. In some cases, top samples resulted in a low risk, while the bottom sample showed a high risk (e.g., vessel V11) or vice versa (vessel V19). The microscope counts of the viable organisms mismatched with the Hach instrument measurements in several cases, e.g., samples from vessels V46 and V49 delivered a Hach result of high risk in all water depths, but the microscope count was only 4 viable cells/ml in V46 and 6 viable cells/ml in V49. A good match occurred for vessels V12 and V15, where the risk indication was high in all three tank levels, and the microscope count was above the D-2 standard (see Supplement 3).

Figure 14 shows the summarized microscope counts of viable phytoplankton cells in the size range ≥10 and <50 µm in minimum dimension of all ports. The highest

phytoplankton abundance was documented in the Ports of Ancona, Trieste and Venice with values above the D-2 standard. In contrast, samples from Bari and Koper showed phytoplankton abundances below the D-2 standard.

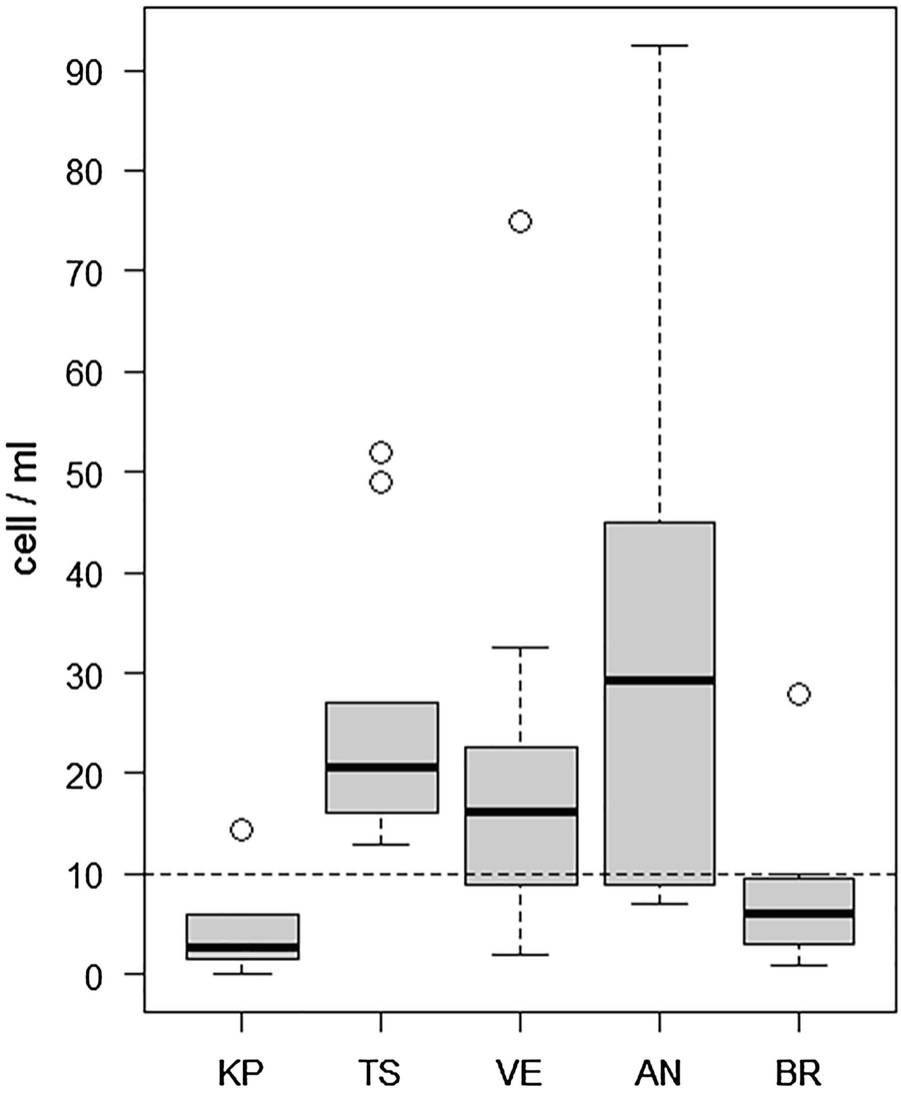

Fig. 14 Counts of viable phytoplankton in the size range ≥10 and <50 µm in minimum dimension detected under the microscope. Integrated ballast water samples were taken on vessels arriving in the ports of Trieste (TS), Venice (VE), Ancona (AN) and Bari (BR). In all cases, $N = 10$. Data for the Port of Koper were added for reasons of comparison. The dashed line at 10 cells/ml represents the distinction between compliance and non-compliance with the D-2 standard. Open circles denote outliers

The abiotic parameters evaluated for 40 ballast tanks showed differences according to the sampling depth (top,

middle and bottom). The highest average temperature (24.8 °C) was measured in the middle of the in-tank water column, while the lowest mean value was measured in the bottom samples (24.1 °C). However, the difference between the highest and lowest mean temperature is less than 1 °C (see Fig. 15).

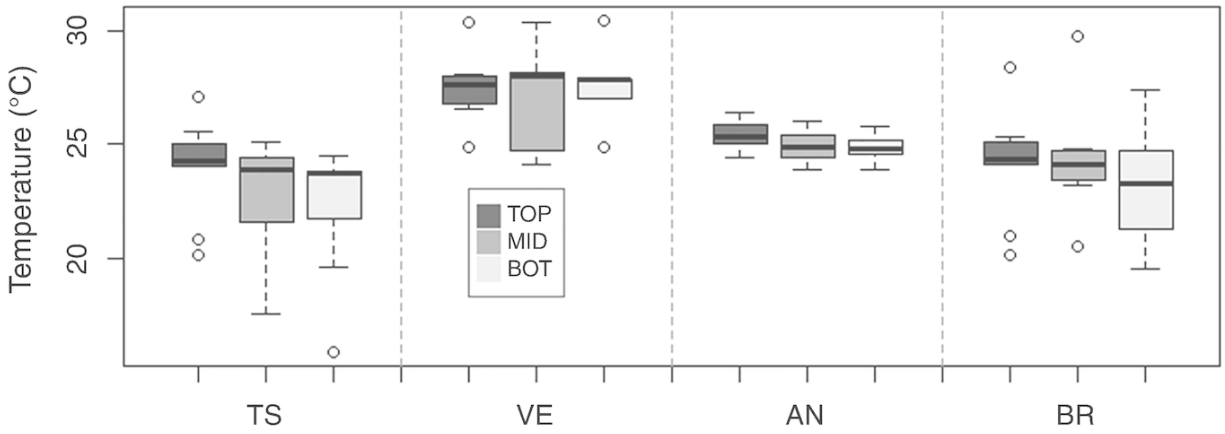

Fig. 15 Temperature of the water samples collected at the top (TOP), middle (MID) and bottom (BOT) of the ballast water tanks. Samples were taken on vessels arriving in the ports of Trieste (TS), Venice (VE), Ancona (AN) and Bari (BR). In all ports, $N = 10$. Open circles denote outliers

4 Discussion and Conclusions

4.1 CME Methods Tests Using En Route Sounding Pipe Samples

During CME method tests on board, we noted in general similar results on both voyages conducted. For many sampling events, we observed that the bottom salinity was highest, which may be because it stratifies as in nature resulting in water with higher salinity at the bottom. On the contrary, in bottom samples, we commonly found the lowest water temperatures compared to top and middle samples of the same sampling event. This may be because of the cooling effect of the ocean the vessel navigated through. Another interesting observation is that on voyage 1, a substantial water temperature drop was observed

during the voyage from the first to the last sampling day. This may also be explained by the vessel's navigational route northwards along the North American east coast into colder waters, entering Chesapeake Bay, clearly documenting that the water temperature in a ballast tank is influenced by the surrounding water temperature. This was also shown in other studies (e.g., Gollasch et al. 2000; Taylor et al. 2007; Klein et al. 2010; Simard et al. 2011; Zaiko et al. 2015).

The indicated phytoplankton abundances by the bbe 10 cells measurements conducted on board were generally higher than phytoplankton counts done after the voyage in the land-based laboratory. This may indicate differences in the measurement principle and the influence of the human element of the bbe 10 cells vs. microscopic analysis, or that sample storage and transport had a negative impact on algae survival. Indeed, microscopic counts were performed even up to 11 days after on board measurements with bbe 10 cells were performed.

We further observed much lower phytoplankton cell abundances on both voyages in tank 1 as an effect of the ballast water management system. It should be noted that the cell abundances are well above the D-2 standard, but this does not indicate a poor performance of the ballast water management system because this system uses UV treatment a second time during discharge of the ballast water. Only checks of the discharged water after treatment was completed, which was not done in this study, would enable BWMS performance evaluations. In this tank, we also observed a decreasing phytoplankton abundance over the sampling days, which may document a delay in the impact of the UV treatment applied during ballast water uptake. Delayed UV treatment effects were also documented in other studies. Other studies documented algae regrowth after UV treatment (Liebich et al. 2012; First and Drake 2013a, b; Casas-Monroy et al. 2016), which

highlights the need for a second application of the UV treatment during ballast water discharge. In contrast, the phytoplankton abundance in the untreated tank increased during the two voyages. It seems that the holding time of the water in the tank has an impact on the distribution of organisms along the water column. Especially during the second voyage, the difference in phytoplankton abundance between the top, middle and bottom samples increased with time, indicating an increasing heterogeneity of phytoplankton in the tank over time. With one exception, we found the highest phytoplankton abundance in the bottom sample, and in many cases the bottom abundance was more than double of what was found in the top sample. In one case (voyage 2, day 4, morning sample), the top sample's phytoplankton abundance, determined by the bbe 10 cells, met the D-2 standard, whereas the bottom, middle and mixed samples would have failed to meet this standard. This indicates the complexity of compliance monitoring with ballast water management standards. We therefore recommend not to base compliance assessments on a single sample and that at least two samples should be taken from a ballast tank, which supports our earlier findings regarding representative ballast water sampling (David and Perkovic 2004; David 2013; Gollasch and David 2017). However, it has to be agreed upon which value will be used for CME purposes: the lowest, the highest or the mean value? We recommend using the mean value of all measurements from a single tank to avoid biased compliance assessment, i.e., not to base compliance conclusions on an under- or over-sampled organism abundance.

Due to the fact that we have data only from two voyages, we would call these corresponding data only as a trend indication unless future studies would confirm our findings.

4.2 Compliance Control Sampling in Adriatic Ports

4.2.1 Sampling Methods According to the Sampling Access Point

Ballast water sampling access points may be divided into in-tank and in-line (at discharge) sampling points. In-tank sampling points enable ballast water access directly from a tank, and this may be achieved either via opened ballast tank manholes, sounding or air pipes. In-line sampling points are located in the vessel's pipework, preferably after the vessel's ballast water pumps.

For D-1 standard compliance monitoring, in-tank or in-line samples may be taken to either prove the presence of coastal biota or for water salinity checks. This may be done by utilizing all possible sampling access points, including sounding pipe, manhole and the vessel's main ballast water line. However, the latter is not recommended to be used because a discharge to sea may most likely occur in this sampling approach, and in case of non-compliance, the non-complaint water would be pumped into the recipient environment during the sampling event. As the D-1 standard is not a numerical organism standard, quantitative biological sampling is not needed.

In contrast, compliance control for the D-2 standard, which is a numerical biological standard, samples should be taken during ballast water discharge from the ballast water discharge line (but see below). Here, a quantitative biological approach is needed as the numerical standard refers only to the number of viable organisms above 10 µm in minimum dimension no matter to which taxonomic group they belong. In contrast, for the indicator microbes as stated in the D-2 standard, both qualitative and quantitative approaches are needed so that the abundance of colony forming units of certain indicator microbes can be documented. Although it seems that in-line sampling is the

most appropriate way to assess compliance with the D-2 standard, this view changes in cases when the ballast water originates from a high-risk area, i.e., an area with a known occurrence of target species. In these situations, samples may preferably be taken from the ballast tank prior to discharge, which would make non-compliance actions possible before the water is discharged into the recipient environment. The in-tank approach is also advisable for D-2 standard compliance checks for those tanks which have direct discharge to sea, e.g., top-side tanks on some bulk carriers.

4.2.2 Sampling for Compliance Control with the D-1 Standard

Salinity measurements of ballast water may be used to verify if the water was exchanged according to the BWM Convention requirements (D-1 standard). Should the measured ballast water salinity be low, e.g., below 30 psu, it can with a high level of confidence be assumed that the ballast water originates from coastal areas with freshwater influence. This means the water was not exchanged with ocean water as required, i.e., outside 50 or 200 nautical miles from nearest land and in areas deeper than 200 metres, because this water would clearly have a higher salinity.

The D-1 standard requires that at least 95% of the water needs to be exchanged. Therefore, up to 5% of water may remain in the ballast tank unexchanged. When a vessel has taken up ballast water in a freshwater port (100% tank volume) and 95% is exchanged in mid-ocean, the possibly remaining 5% freshwater in the tank will dilute the salinity of the ocean water taken up during the exchange. As a consequence, this salinity dilution may result in a false non-compliant indication in cases when the remaining freshwater from the previous tank filling would be ignored.

From our on board studies, we know that sometimes more than 5% of water remain as unpumpable ballast inside ballast tanks.

Our study has shown that the salinity of the ballast water in a ballast tank was not homogeneous when the salinity was measured over different depths of a sounding pipe. In previous studies, we also noted this when a salinity sensor was lowered in the sounding pipe (Gollasch et al. 2012). The closer to the tank bottom the samples were taken, the higher was the salinity. Further, during ballast water discharge of this vessel, the salinity was measured over time at a sampling point in the vessel's main ballast line, and over time, i.e., towards the end of the tank emptying process, the salinity value increased (Gollasch et al. 2012).

During the sampling events in all ports, the highest salinity values were observed in the bottom samples taken through the sounding pipes. However, considering the mean values over all samples in Slovenia, the middle and bottom salinities were observed in similar values, and the top samples had the lowest salinity with a difference of slightly more than 1 psu. In Italian ports, the top and middle salinities were similar and were slightly less than 1 psu lower than the bottom salinity.

The results presented here and our previous studies give a clear indication that salinity sampling for compliance control is not trivial and that more than one sample may need to be taken to cover potentially varying salinities of ballast water in the same tank. This may be done either by lowering a salinity meter to different depths in a ballast tank or by taking multiple samples in the sounding pipe from the vessel's ballast water discharge line during the water discharge of the tank, although the latter can only be done during ballast water discharge.

Documenting the presence of certain biota as a D-1 standard compliance control test is also of a limited value,

and the weaknesses of this approach were already described (Gollasch et al. 2012; Gollasch and David 2015) and include (a) species occurrence is rarely restricted only to coastal waters, (b) “contamination” may occur by organisms re-suspended from the tank sediment and (c) the presence of faecal bacteria may indicate the ballast water was exchanged in coastal areas with insufficient sewage treatment, but they may also occur in the open water or may be carried by other organisms (Grimes and Colwell 1986; Wait and Sobsey 2001; Whitman et al. 2003). Another method would be to document tracers of human influence on the sea in the ballast water on board (Murphy et al. 2008). Candidate substances to check include nitrogen and phosphorous levels or chromophoric dissolved organic matter (CDOM). Elevated levels of nitrogen and phosphorous may be generated by water run-offs in urban areas with less efficient water treatment systems, indicating coastal origin of the ballast water. Elevated levels of chromophoric dissolved organic matter (CDOM) may also indicate coastal origin of water as CDOM is a product of decayed (terrestrial) plants. Here it is the premise that the CDOM concentration is the highest nearshore and decreases with increasing distance from shore. Theoretically, the concentration of these substances would be higher due to river run-offs in areas with high human population, indicating that ballast water with elevated concentrations of aforementioned substances was exchanged close to the coast (Murphy et al. 2004, 2006, 2008; Hunt et al. 2007). However, in oceanic island states or in coastal environments with low human populations, the levels of these substances may be very low even close to shore so that ballast water might have been exchanged close to land, but this cannot be confirmed by measuring the concentration of these substances.

As shown above, the analysis of the biota for D-1 standard compliance control delivers results only with a

limited level of certainty. Therefore, in cases when non-compliance is indicated by these methods, we believe that these data are not robust enough to justify a non-compliance action with all its logistical, costs and legal implications.

Because of all limitations stated above, biological sampling is not recommended for D-1 standard compliance control. The non-biological methods also seem to generate results with low confidence levels, so that only the measurement of ballast water salinity seems to be a pragmatic option to check the compliance with the D-1 standard. However, in the present study, all vessels which loaded ballast in marine ports would always be in compliance when using this method. Therefore, salinity D-1 standard compliance checks should be done together with checking the vessel's logbook and the salinity in the ballast water uptake port(s).

4.2.3 Sampling for Compliance Control with the D-2 Standard

Compliance control with the D-2.1 standard is purely quantitative, thereby ignoring the taxonomic groups of organisms, with the exception of faecal indicator microbes and pathogenic *Vibrio cholerae* (D-2.2 standard). The numbers of viable organisms per size class document (non-)compliance. As the BWM Convention in Regulation D-2 reads "Ships conducting Ballast Water Management in accordance with this regulation shall discharge less than 10 viable organisms per m^3 ...", the D-2 standard is clearly understood as a discharge standard. This indicates that the most appropriate sampling point to prove D-2 standard compliance has to be installed in the discharge line of the vessel's ballast water system. This is also recommended in the Guidelines G2, i.e., "samples should be taken from the discharge line, as near to the point of discharge as

practicable, during ballast water discharge whenever possible". However, in-tank sampling should also be considered as a valid option for D-2 standard compliance control. This is because some vessels, e.g., certain bulk carriers and tankers, may have upper side wing tanks which are emptied via direct overboard discharge valves and not by using ballast pumps and pipework. In such cases, Guidelines G2 indicate that in-tank sampling may be an appropriate approach.

4.2.4 Indicative Sampling for Compliance Control with the D-2 Standard

The indicative sample analysis is addressed in Guidelines G2. Paragraph 6.3 reads: "Prior to testing for compliance with the D-2 standard, it is recommended that, as a first step, an indicative analysis of ballast water discharge may be undertaken to establish whether a vessel is potentially compliant or non-compliant." However, Guidelines G2 do not address explicitly how an indicative sampling event would need to be conducted.

One important point to note is that an indicative sampling event may be targeted towards only one group of organisms addressed by the D-2 standard. The results from each of these organisms' groups alone may already be taken as an indication that the ballast water management system is not performing properly. From our experience of on-board ballast water sampling, phytoplankton analysis may be the only validated indicative analysis method available today. This is because PAM instruments deliver an estimation of the organism abundance in minutes and a small volume of water is sufficient for the analysis.

Depending on their size and abundance, different groups of organisms require different sampling approaches. In general, organisms greater than or equal to 50 µm in minimum dimension require larger water volumes to be

sampled compared to organisms less than 50 µm in minimum dimension and greater than or equal to 10 µm in minimum dimension. Consequently, indicative sampling methods may differ in sampling duration, timing, volume and further in the recommendation of which sampling point is to be used.

Another issue to consider is the consequences which may arise from an indicative sample analysis. Does an indicative D-2 standard test result trigger the need for further tests, i.e., a detailed D-2 standard compliance test? Or should a vessel be banned from discharging ballast water solely based on the indicative test result? Based on paragraph 6.3 of the G2 Guidelines, it is understood that an indicative analysis was included to give a Party an opportunity to identify potential non-compliant ballast water in an early stage. This is because the detailed compliance test may show results only after all ballast water was already discharged, and therefore the indicative analysis was implemented to avoid any impact from possibly non-compliant ballast water discharges from a vessel due to prompt non-compliance actions.

4.2.5 Phytoplankton Below 10 µm

We identified relatively high abundances of viable phytoplankton in the size range <10 µm compared to the organisms in the size range ≥10 and <50 µm in minimum dimension in the same samples. The BWM Convention D-2 standard does not consider these organisms at all (IMO 2004), which we see of concern as species in this size class include Harmful Aquatic Organisms and Pathogens (HAOP). For example, the harmful bloom alga *Aureococcus anophagefferens*, which is 2 µm in dimension, was found in ballast tanks (Doblin et al. 2004; Gobler et al. 2011), and cysts of some toxic and non-toxic dinoflagellates are <10 µm (Doblin and Dobbs 2006). We therefore

recommend that IMO addresses this aspect should the D-2 standard be renegotiated.

4.2.6 Other Physical Parameters

The mean values of all temperature data showed smaller vertical differences in the sounding pipes compared to salinity. In the samples taken in Koper, the mean temperature was nearly the same in all sampling locations (top, middle and bottom), whereas in Italy, the temperature decreased slightly from top to bottom. The Koper and Italian port differences in temperature may be related to the season when the sampling events were conducted. The samples in Koper were taken in winter when air temperature and water temperature are closer compared to the summer situation during which the Italian ports were sampled. As stated above, the water temperature in a ballast tank is influenced by the surrounding water temperature (Gollasch et al. 2000; Taylor et al. 2007; Klein et al. 2010; Simard et al. 2011; Zaiko et al. 2015), and we believe that warmer air temperature and especially sun exposure will also have an influence on the water temperature in a ballast tank. Gollasch (1996) observed a similar trend during his four-year ballast water sampling programme with monthly sampling events on almost 200 vessels in German ports.

During the Adriatic port sampling events, critical low oxygen values for some zooplankton organisms were found, and this was also found in other ballast tank sampling studies (Klein et al. 2010; Zaiko et al. 2015). However, certain species, such as *E. coli*, does not require oxygen, but develop better in the presence of oxygen (Gregory and Fridovich 1973; Caruso et al. 2015). This means that when oxygen is low, as in some of the top samples, the top layer may have less oxygen-dependent organisms than the bottom sample. Further, the creation of anaerobic

conditions may result in the accumulation of facultative anaerobic bacteria, and this may represent a habitat for pathogenic species (Joachimsthal et al. 2003). In addition, the different oxygen content measured at different depths along the same sounding pipe clearly document the difference in abiotic conditions from top to bottom samples, and this difference is stronger compared to changes in salinity and temperature. This clearly documents the non-mixed water conditions inside the sounding pipe.

As others (Gollasch et al. 2000; Murphy et al. 2002; Taylor et al. 2007; Carney et al. 2013; Gollasch and David 2017), we have shown that organisms are not homogeneously distributed in ballast tanks so that compliance control sampling becomes a challenging task. We therefore conclude that compliance control sampling should be based on at least two samples taken from different depths provided that in-tank sampling is accepted for the purpose of proving compliance with a ballast water discharge standard.

Acknowledgements

The results in this publication have been produced with the financial assistance of the IPA Adriatic Cross-Border Cooperation Programme—strategic project Ballast Water Management System for Adriatic Sea Protection (BALMAS). The contents of this publication are the sole responsibility of authors and can under no circumstances be regarded as reflecting the position of the IPA Adriatic Cross-Border Cooperation Programme Authorities.

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© Springer Nature Switzerland AG 2024
M. David, S. Gollasch (eds.), *Global Maritime Transport and Ballast Water Management*, Invading Nature - Springer Series in Invasion Ecology 16
https://doi.org/10.1007/978-3-031-48193-2_7

Ballast Water Management Options in Ports

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Abstract
The Ballast Water Management (BWM) Convention requires vessels to discharge ballast water according to its requirements, and with this, vessels are obliged to manage the ballast water to be discharged properly. However, due to different reasons, ballast water may not be managed properly. The reasons may be numerous but commonly include technical failures of the Ballast Water Management System (BWMS) or inclement weather. The BWM Convention requires port State authorities not to allow ballast water discharge in such cases. If this is the case, port State authorities would need to have an adequate alternative management option to offer. So far, different BWM options are considered in the relevant literature but also examined in practice. Although underlying

technologies are almost identical to those implemented onboard merchant ships, the necessary conditions, requirements, and business models are significantly different when comparing onboard solutions with port-based BWM options. Therefore, this chapter discusses the conditions, requirements, and economic viability of these alternatives.

Keywords Ballast water management – Non-compliance – Port reception facility – Shore-based treatment – Barge-based treatment

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1 Introduction

According to the International Convention for the Control and Management of Ships' Ballast Water and Sediments, 2004 (BWM Convention),[1] "each Party shall require that ships to which this Convention applies and which are entitled to fly its flag or operating under its authority comply with the requirements set forth in this Convention, including the applicable standards and requirements in the Annex, and shall take effective measures to ensure that those ships comply with those requirements" (Article 4).

Being mandatory for ships in international trade, the BWM Convention presumes that BWM is carried out onboard ships by appropriate practice or shipboard equipment, i.e., ballast water management system (BWMS). Consequently, in case of violations, the BWM Convention provides two different lines of action: one to be carried out by the Party whose flag the ship is entitled to fly or operate under the authority of the Party, and the other by the Party in whose port or offshore terminal the ship is operating.

The actions that may be undertaken by the Party whose flag the ship is entitled to fly are in their essence legal actions; the Party has to implement the proceedings in

accordance with its law, and sanctions “shall be adequate in severity to discourage violations of this Convention wherever they occur” (Article 8). In addition, it may warn, detain, or exclude the ship.

The situation is much more difficult for the Party in whose port or offshore terminal the ship operates. It may grant “permission to leave the port or offshore terminal for the purpose of discharging ballast water or proceeding to the nearest appropriate repair yard or reception facility available, provided doing so does not present a threat of harm to the environment, human health, property or resources” (Article 10). A different action is assumed if the ballast water sampling indicates that the ship poses a threat to the environment, human health, property, or resources. In such a case, the Party shall prohibit such a ship from discharging ballast water until the threat is removed. The same applies in case a ship is not carrying a valid certificate or if there are clear grounds for believing that the condition of the ship or its equipment does not correspond substantially with the particulars of the certificate, or the master or the crew is not familiar with essential shipboard procedures relating to BWM or have not implemented such procedures (Article 9.2). If so, the ship shall not discharge Ballast Water until it can do so without presenting a threat of harm to the environment, human health, property, or resources (Article 9.3).

Such outcome in most cases means a significant financial loss for a shipping company (leaving a port without loading or unloading the cargo, missing next cargoes, etc.) but also for shippers (cargo not being delivered), port operators (loss of profit), and cargo owners (cargo not received on time). Consequently, such actions must be justified and their reasoning clearly communicated to all involved to avoid pending legal actions and additional costs. If such circumstances repeatedly occur, or if actions carried out by the Party are generally considered as

inappropriate, the shipping companies may stay away from that port or even a country and select alternative transport routes, thus causing substantial profit losses, which at the end would significantly disturb the local or even regional economy.

Consequently, ports need to develop an exit strategy for cases when commercial operations are jeopardised by ships carrying ballast water deemed not properly managed and posing a threat to the environment, human health, property, or resources. The possible contingency measures are discussed in this chapter.

In this chapter, the following terms are defined as follows:

- Maritime Administration—the Government executive body responsible for maritime safety, security, and pollution prevention.
- Port authority—a Governmental or quasi-Governmental public authority, usually appointed by a legislative body (or bodies), and responsible for efficient operations of the port and other related transportation infrastructure; may commercially operate shipping terminals and related facilities.
- Port operators—the legal entity, usually profit-oriented, responsible for cargo operations within a port area.
- Company—the owner of the ship or any other organisation or person such as the manager, or the bareboat charterer, who has assumed the responsibility for the operation of the ship from the owner of the ship and who on assuming such responsibility has agreed to take over all the duties and responsibilities imposed by the International Safety Management Code (BWM Convention, Annex, Regulation A1—Definitions).

2 Legal and Organisational Framework

According to the BWM Convention, a ship must treat ballast water in a shipboard BWMS (satisfying standards described in Regulation D-2) or deliver untreated ballast water to a port reception facility.

The Guidelines for ballast water reception facilities (G5) (IMO 2006) specify fundamental requirements for reception facilities. According to the Guidelines G5, “a ballast water reception facility should be capable of receiving ballast water from ships so as not to create a risk to the environment, human health, property, and resources arising from the release to the environment of Harmful Aquatic Organisms and Pathogens. A facility should provide pipelines, manifolds, reducers, equipment, and other resources to enable, as far as practicable, all ships wishing to discharge ballast water in a port to use the facility.”

The Guidelines require reception facilities disposing ballast water into the aquatic environment to meet at least the ballast water performance standard specified in Regulation D-2 of the BWM Convention. For disposal elsewhere, ballast water should be treated to a standard acceptable to the port State. In addition to the prearrangement of ballast water reception facilities and requirements dealing with treatment and disposal of received ballast water, Guidelines G5 indicate the capabilities of a reception facility and the required training of the facility personnel. The Guidelines G5 have no requirements indicating capacities or technology to be used. They are left to the port States to design and implement.

Based on the BWM Convention requirements and recommendations outlined in Guidelines G5, each port State should develop national policies, strategies, or

programmes for BWM in its ports and waters, considering prevailing conditions and capabilities (Anstey 2008; Ta-Kang et al. 2014). National policies and strategies should outline the national goals and roles of main stakeholders. In the case of the enclosed sea areas, e.g., the Adriatic, Black, or Baltic seas, the policies and strategies have to include interests of neighbouring countries because the effective implementation of measures to control the transfer of harmful aquatic organisms and pathogens in such sea areas significantly depends on international cooperation and harmonised implementation of the BWM Convention.

Policymakers are expected to decide primarily on the port State's role regarding the availability and operations of the reception facilities and other measures associated with proper BWM. Regarding reception facilities, the decisions may range among the following options:

- the port State fully supports the installation and operations of reception facilities;
- the port State partially supports the reception facilities, e.g., by providing financial means for equipment, premises, and installation, while running costs being covered by users;
- the port State is not involved in the development and operation of reception facilities, and the users have to cover all costs.

In the first case, all costs (capital and operational) are covered by the port State. In this case, the ports where such an approach is implemented have significant advantages compared to ports where such service is not provided. Ships calling at these ports will be able to complete the voyage and deliver the cargo, even when the BWMS on board was malfunctioning, or BWM was not deemed to be satisfactory due to other reasons. The service may be offered at no cost or at a certain fee unrelated to the actual costs.

In the second case, although the port State provides significant support, the service offered to the ships is a profit-oriented venture and assumes that ships using the service will compensate for operational expenses. The approach supposes that a legal entity (usually only one) enters contractual relation with the port State and assumes responsibility for the service for a certain period. In this case, the fee for the service is expected to relate to actual costs. However, the coverage of actual costs depends on the port State's willingness to invest and ensure the service. In some cases, the port State may be willing to cover expenses higher than the income of such a facility (in this case, the service may be considered a public service, not a profit-oriented venture).

The last case assumes that reception facilities are operated as a commercial, profit-oriented venture. The legal entity (or few legal entities, if demand is sufficiently high) may offer the reception of ballast water from ships as a fully paid service. The fee is supposed to cover all expenditures and provide a certain profit margin. Consequently, the overall profitability of the venture depends on the number of ships using the service and ballast water quantities. Since most BWMS are designed to provide high reliability and long maintenance-free working times, the demand for reception services is not expected to be high, even in the busiest ports. Consequently, the ports with low traffic volumes would not be attractive for private investors and may be left without reception facilities. In this case, ships not able to properly treat ballast water are exposed to potentially high expenditures if their ballast water is considered a threat to the environment, human health, property, or resources.

From an organisational standpoint, the services may be offered by:

– a port operator (mostly as a service to their actual or potential clients);
– a port authority; or
– independent private companies.

The first case is justified if a particular port operator has exclusive rights, i.e., it is responsible for all port operations across the entire port area, usually based on a concession agreement. In a way, such service is one of the public services offered to ships using the port. When several operators offer cargo or passenger operations within the same port area, the port authorities, if existing, are the more appropriate subject to offer such service to ships being handled by different operators. Finally, it might be an independent company, not related to port activities, trying to make a profit by offering ballast water reception as a service.

Use of the ballast water reception facilities are considered by masters and ship operators mostly in two cases: (1) when a shipboard BWMS is not operational (due to malfunction or other reasons), and (2) when the company deliberately decided not to install the shipboard BWMS and to use the port reception facilities as an economically more viable option.

When the shipboard BWMS is not operational, and ballast water is not compliant, contingency measures are required. According to the Guidance on contingency measures under the BWM Convention (IMO 2008, 2017), options to be considered by the ship and the port State are:

– actions predetermined in BWM plan of the ship;
– discharging ballast water to another ship or appropriate shipboard or land-based reception facility, if available;
– managing the ballast water or a portion of it in accordance with a method acceptable to the port State;
– ballast water exchange carried out to an approved plan in accordance with regulation B-4 to meet the standard

in regulation D-1;[2] or
- operational actions, such as modifying sailing or ballast water discharge schedules, internal transfer of ballast water or the retention of ballast water on board the ship.

In such circumstances, the port reception facility is probably the most attractive measure if available. If there are no reception facilities or facilities are not available at the time, the second-best measure would be the one requiring the least expenses but still be acceptable by the maritime Administration of the port State.[3]

Port reception facilities are also a viable solution when ships are in international trade and are not equipped with the BWMS (COWI 2012; Tjahjono and Handoko 2018). It might be the case if:

- installation of the equipment on board existing ships is considered too expensive or technically challenging, or
- the company running the ship deliberately decides not to equip the ship and plan to use port reception facilities offering lower costs per volume unit of the ballast water loaded/unloaded.[4]

In both cases, the ship is assumed to trade on an international (regular) route, calling only at ports where reception facilities are available. The viability of such trading also depends on the reception facilities' suitability, capacities, and BWM fees. The main disadvantage of such an approach is the low flexibility of such trading routes, particularly regarding ports the ship can call.

Regarding the second case, it is assumed that at least several ships are regularly using the same reception facility; otherwise, the costs of such arrangement are the same or even higher than they would be in case of a shipboard installation of a BWMS.

In both cases, the main disadvantage is the low flexibility of such a trading pattern, particularly in respect

of ports the ship(s) can call.

Finally, it needs to be emphasised that the decision to install and maintain the port reception facility depends on the number, size, and types of ships predominantly using the port and the port features. In that respect, installation and maintenance of the reception facilities are justified in ports where:

- quantities of ballast water to be discharged are sufficient to ensure economically viable operations, i.e., larger ships, predominantly cargo loading, regular/frequent calls or
- responsible authorities decided to ensure proper BWM in case ballast water is not compliant and at the same time enable efficient port operations.

In ports without ballast water reception facilities, the responsible authorities should consider other contingency measures in case of non-compliant ballast water occurs and be aware that in such cases, the port and ships may incur additional costs.

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3 Port Ballast Water Reception Facilities and Treatment Methods

Port-based BWMS can receive untreated ballast water from ships, treat it, and dispose of it safely within the port area or to other users, e.g., water stored in land-based tanks may be used as ballast water on another ship.

Port-based systems use the same core methods as onboard systems but are customised to use in ports. The port-based system may be developed as one of the following (COWI 2012; King and Hagan 2013; Rata et al. 2018):

- land-based systems, having BWMS located on the shore; ballast water is transferred from a ship to the shore unit

using a pipeline or a collecting barge;
- barge-based systems, with BWMS located on the barge (either a self-propelled or towed barge), with or without storage capacities on the barge;
- truck-based mobile BWMS, where the treatment plant is mounted on a flatbed trailer; or
- desalination plants.

At present, most ships do not have arrangements to discharge ballast water to a port-based ballast water reception facility. To use a port-based system, the shipboard ballast system must be capable of pumping-out ballast water through deck-mounted piping with adequate couplings. The piping arrangement on board shall provide the discharging manifold near the ship's side, at least 1 m above the quay level when the ship is fully loaded at low water. The ship's ballast pumps normally provide working pressure of at least 3.0 bars at sea level, while pressure at a high-level discharge outlet shall be at least 1.5 bars to ensure the proper operation of BWMS unit on the quay. Discharge outlets should be provided on both sides of the ship and located preferably near the stern, thus providing easy connection in case of different berth conditions. Also, the lifting devices for handling the hose should be available, but this could also be arranged at the reception facility (Fig. 1).

Fig. 1 The shore-based application of a mobile BWMS (The system presented is developed by Bawat, Denmark (https://www.bawat.com/mobile-bwms/mobile-bwms/). Last accessed in March 2024)

3.1 Land-Based Reception System

Land-based reception systems are systems having BWMS located ashore. It is coupled with one or more terminals with pipelines (Fig. 1), including auxiliary pumps if required. Land-based systems, as a rule, may use any of the treatment methods (or their combination) usually used on board. Treatment facilities should be located as close as possible to the ship berths to keep the connecting pipelines not too long, thus minimising the capital expenses.

Another option is to use a barge, or a ship, instead of the piping. In this case, a large ‘collecting barge’ should transfer the untreated ballast water to the land-based BWMS. The capacity of the barge must at least exceed the largest ballast quantities that may be discharged from the largest ships in a given port.

The land-based system may be designed with or without storage tanks. The system without storage tanks (flow-through system) implies that the untreated ballast water is collected from the ship, treated on the barge at the same rate it is pumped, and discharged in the sea. The system using storage tanks requires a much larger land area[5] and

capital expenses but offers flexibility and additional services. Firstly, shore-based storage tanks may be used as buffers, i.e., the ballast may be collected from the ship and stored much faster, independently of BWMS flow rate. Secondly, instead of being discharged, the treated ballast water may be stored and kept as clean ballast water to be loaded on another ship that cannot comply with the BWM Convention (Kontovas 2019). Such treated ballast water, loaded at the port of departure, would not require further treatment at the destination port.

The concept of reusing the treated ballast water at the port of departure could be feasible if maritime authorities of the destination port would accept treated ballast water as being compliant and allow the ship to discharge such water (COWI 2012). This concept would require an internationally accepted procedure or a certificate system.

In general, the advantages of the land-based system are:

- greater flexibility in the selection of technology—there are no space restrictions;
- higher treatment capacity—land-based systems may be designed for any capacity that may be needed, only being restricted by the selected technology;
- greater operational flexibility—systems are operated by well-trained staff, and there are no restrictions regarding safety systems to be used to control operations;
- greater power flexibilities—main electrical lines may be used as the main power source as well as independent power generators;
- better maintenance—technically sensitive elements are easier to maintain or to keep them redundant;
- better waste control—treatment process and residuals (or their disposal) are easier to provide and/or control.

The main disadvantages are:

– choosing the location of BWMS might be quite challenging due to limitations of the port areas available for such purpose, particularly ports encircled with urban areas;
– number of berths as well as distances between terminals and BWMS may limit the application;
– even in the case of high ballast-dependent vessels, the system could be highly under-utilised;
– the facility may be subject to additional requirements (such as environmental impact assessment) to prove that the facility is environmentally sound.

3.2 Barge-Based Reception System

A barge-based reception system consists of a BWMS installed on a barge or a ship. As an alternative to the land-based system, the barge-based system can serve ships within a much larger port area, including anchorages. The system does not depend on the port infrastructure and has minimal interferences to loading/unloading operations since the barge berths alongside the ship being serviced.

It is built as a smaller barge with BWMS on board and can be either self-propelled or towed. Barge-based systems generally might use any approved BWMS methodologies (or their combination).

The advantages of using a barge-based system are:

– usage at different locations, including at anchorage (weather permitting);
– effective use of BWMS that may not be economically viable in case of land-based systems (smaller capacity, independent power supply);
– no need to install a pipeline system;
– no occupancy of space in a port for storage tanks etc.;
– effective use due to the qualified staff responsible only for BWMS.

The disadvantages of the use of barges are:

– additional costs for barge fuel and maintenance;
– under-optimal operations—in case of a low capacity system installed on the barge, delays are highly probable when servicing the high ballast dependent ships; if the high capacity system is installed, it will be underutilised except in case of servicing high ballast dependent ships; the issue may be dealt with in case of modular installations;
– delays are probable in case of concurrent requests or barge systems' malfunction.

3.3 Mobile Land-Based Reception System

Mobile land-based systems are systems where BWMS is installed on a truck or a similar vehicle capable of receiving and treating the ship's ballast water. The assumed systems are mostly based on filtration (mechanical cleaning with backflushing) and UV irradiation (disinfection) technology, including treatment with self-produced ozone (as a by-product of UV treatment), thus providing better results in case of high concentrations of suspended solids or under near-fresh water conditions (Jang P-G et al. 2020).

The equipment may be installed in a standard 20′ container, mounted on a 40′ flatbed trailer, with a tug or truck unit for hauling in the ports and on the roads (Fig. 2). If there are restrictions on power use in the port, it will require an independent power source at the quay. The independent power supply may be a generator mounted on the trailer. The system should be equipped with a tank to collect backflushing slurry from the filters. The quay must be able to support the total weight of the treatment equipment and trailer.

Fig. 2 A mobile BWMS (The system presented in the figure is developed by Bawat (https://www.bawat.com/mobile-bwms/mobile-bwms/), but there may be other producers of such systems. Last accessed in March 2024)

During deballasting, ballast water may contain suspended material, the quantity of which depends on the sea area where ballast water was loaded and the rate of sedimentation. Consequently, backflushing material collected during treatment may be returned to the tank(s) or retained. If the slurry is retained, it must be properly stored because it may still contain viable aquatic organisms that escaped the treatment or resting stages that could not be treated by BWMS. Consequently, the system needs approval from the local environmental authorities.

Disinfection of the residue material could be achieved by chlorination in reception tanks in which the slurry shall be kept for at least 24 h. Afterwards, it could be deposited for settlement in storage tanks. After settlement, the residue should be inspected for viable organisms and contamination with chemicals, and it might be delivered to a controlled depot or a land reclamation area.

It should be noted that for the moment, no regulations or guidelines dealing with such generated waste disposal (slurry, solid residues, or sediments) from BWMS of ballast

water reception facilities are identified (see chapter “Ballast Tank Sediment: A Neglected Subject Which Requires Management”). However, such regulations should be expected in time (Maglic et al. 2018). Here, it is assumed that generated waste should be treated the same way as sediments unloaded from ships (GloBallast Partnerships 2017).

The advantages of mobile land-based systems are:

- flexibility regarding berths where it can be used, including neighbouring ports;[6]
- high mobility, particularly in respect to barge-based systems;
- independent power supply;
- simple operations and maintenance.

The main disadvantages are:

- limited capacity making the system effective only for low ballast dependent vessels; otherwise, undue delays may be expected;
- limited applicability for ships or terminals where the area next to the ship is used for cargo manipulation (e.g., container cranes).

3.4 Desalination Plants

Another option is to treat the ballast water in existing or future desalination plants (Donner 2010). Desalination plants are built worldwide to provide fresh water to regions where freshwater is limited. Such plants can be found in, e.g., the United Arab Emirates, Israel, Australia, USA, Mexico, and Brazil. There are two principal desalination methodologies, thermal treatment and reverse osmosis. The thermal treatment separates organisms and salt from seawater by evaporation, and reverse osmosis by high-pressure osmosis of seawater through filters and membranes. Both alternatives have proven successful in

removing organisms (Pereira et al. 2017) so that either ballast water received from a ship may be treated this way or that desalinated water is donated to vessels as ballast water. It is also possible to add chemical substances before and after processing seawater to remove all organisms. This method, although possible, is not expected to be widely accepted as it may only be feasible in ports close to high freshwater demand areas and where the power to run such facilities is sufficiently available in a cost-competitive way.

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4 Practicability Tests of Port Reception Facilities

Port reception facilities were tested in several ports in Europe, including a variety of port profiles and sizes. A mobile land-based BWMS is in routine operation in the Port of Antwerp, where it services a customer and their different vessels.[7] A preliminary test of a land-based BWMS was run in the port of Hamburg in 2019.[8] The system was installed on a barge and run by a local operator company. The flow treatment rated capacity was 300 m^3/h. During the 3-month testing phase, several performance test runs were conducted as sea-to-sea tests, and ballast water of three commercial ships was also treated (Jung 2020). Technical problems occurred, mainly involving the piping between the ship's ballast water system and the reception facility. However, the Environmental Protection Body of Hamburg expressed sympathy for such a system as to how would otherwise non-compliant ballast water permitted to be discharged in the port. Therefore, it was concluded that, despite the observed problems, this approach is to be considered further as it is seen to be much better than the 'do nothing' option.

5 Economic Viability of Port Reception Facilities

Implementing a port reception facility only makes sense if the services offered will provide sound protection of the environment at reasonable costs. The economic viability analysis may help to decide whether installing and running a ballast water reception facility is a good use of public resources, or it can be even offered as a profit-making service, or, in a worst-case scenario, it should not be implemented at all, and other options need to be considered. In that respect, a port reception facility is considered economically viable if the economic benefits of its installation and running exceed its economic costs when analysed for society as a whole. This section describes such analyses as applied to potential port reception facilities, highlighting key issues that would typically be addressed to make an informed decision.

Consequently, the legal entity considering procurement, installation, and maintenance of the reception facility should test (Tjahjono and Handoko 2018) its viability through technical and economic appraisal (Fig. 3), as any other major public project. In that respect, there are several steps to be followed.

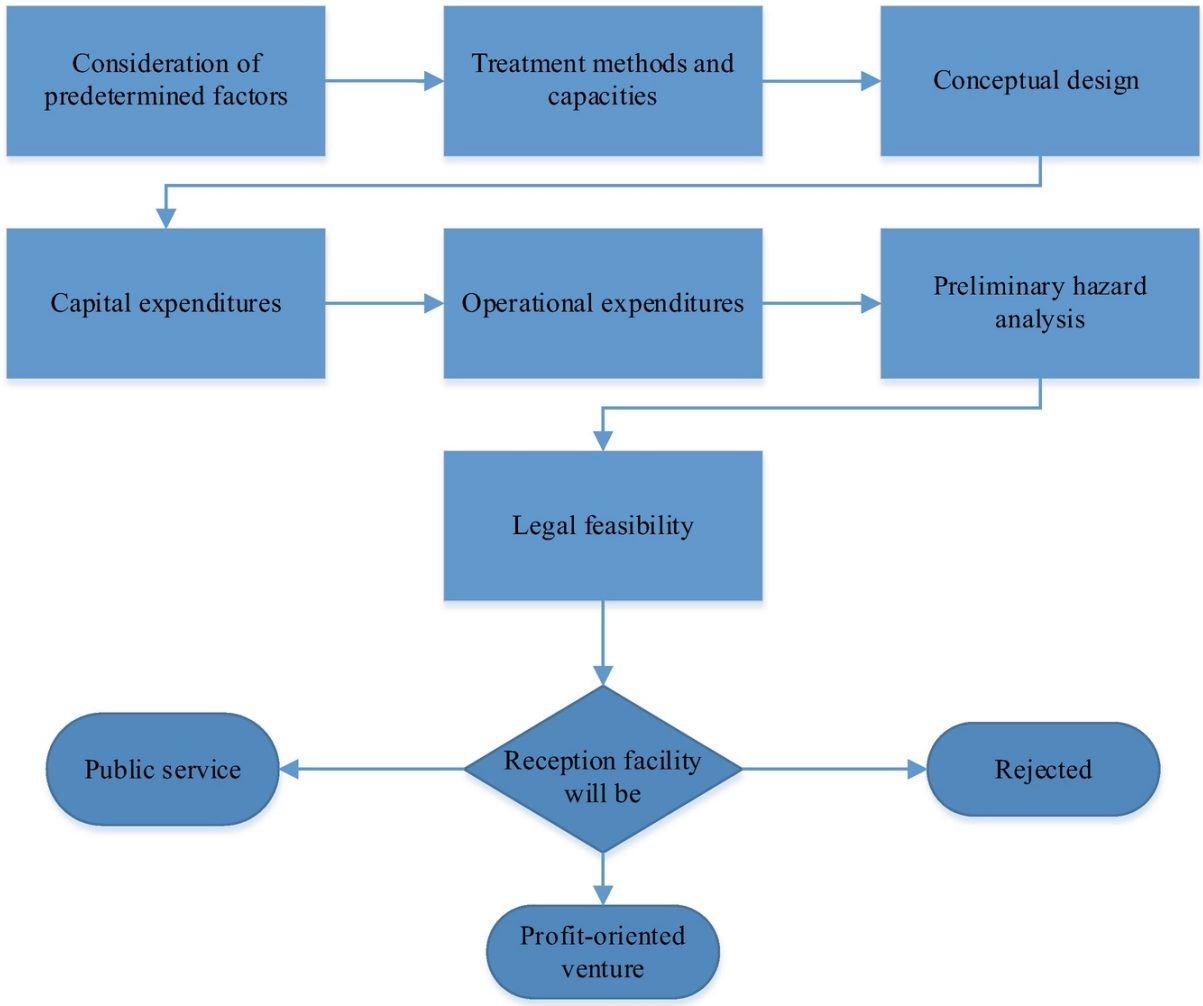

Fig. 3 Technical, economic, and legal appraisal of the port reception facility

Technical feasibility is the initial step in the economic viability analyses. It should consider designing aspects and, in the end, answer the question of whether the project can be implemented as planned, using designed technologies, and without unreasonable technical risks. Subsequently, the following predetermining factors need to be considered:

- the predominant type and size of ships, including the largest ship that may be reasonably expected in the port;
- predominant geographical ballast water sources (bioregions, time onboard, quantities, etc.);

– maximum and average treatment capacities (including the probability of concurrent requests);
– available time to complete treatment (and not causing undue delays to ships);
– modes of connecting ships' ballast systems and reception facility;
– ballast water storage requirements, if any;
– required seaworthiness (for shipboard/barge systems);
– location (lay-up position) and port configuration.

The next step is to consider the treatment methods and associated capacities. Treatment methods should be selected considering the required footprint, environmental risks (Werschkun et al. 2014), the time required for destruction of organisms and safe discharge, the impacts on other systems or structures (corrosion), reliability, serviceability, etc. Each treatment method has its advantages and disadvantages. This is very much the case if the effectiveness is checked against different microorganisms (or groups of microorganisms) or in different environmental conditions (Pazouki et al. 2011). Most of the methods clearly showed relatively high efficiency in treating certain types or sizes of organisms while somewhat minor or even complete inefficiency in respect of others.

Consequently, many presently approved solutions are based on a combination of two or three compatible methods. Filtration is the most commonly used primary method, while in the next stage, other methods are used (such as chemical treatment and ionisation, or UV radiation combined with oxidation). It is worthwhile to emphasise that the performance of BWMS may change depending on the quality of the water, flow rate, quantity of the water to be treated and time available to treat ballast water (LR 2015; IMO 2020).

The capacity of the ballast water reception facility, in general, should be at least capable of accepting ballast

water from the largest ship at its maximum cargo loading rate, thus avoiding undue delays. Although considered rare, concurrent requests may happen, with higher probability in certain periods of the day, e.g., within 2 h after loading commences and loaded quantities reach the level requiring deballasting. If such probability is not negligible, then total capacity should be increased.

The quantity of ballast water delivered by a ship strongly relates to the type and size of the ship. In that respect, ships can be separated into two distinctive groups. The first group consists of ships carrying large quantities of ballast water on board, such as tankers and bulk carriers. The high-capacity pumps on board these ships are designed to unload large quantities of ballast water in a relatively short time. The second group consists mainly of ships that do not load large quantities of ballast, such as container ships, general cargo, and passenger ships. These ships usually load or unload only a portion of ballast water carried on board, mostly to trim the ship. The installed capacities of the ballast pumps on these ships are considerably smaller.

The next step is the conceptual design of the ballast water reception facility. In that respect, the most important decision is whether the facility will be fixed or mobile. If a fixed facility is selected, its location, supply methods, and footprint should be selected. In the case of mobile units, the transport mode needs to be determined. The available solutions include barge-based or truck-based units. For each one, the laid-up location(s) must be decided.

The following step in the process is to estimate the main expenditures for each option (if more than one is selected). The factors affecting the financial viability are:

– purchase price (core system price), including procurement costs;

– position costs (land, for shore-based systems, or barge, for barge-based systems);
– installation costs;
– energy consumption and costs of energy and supplies, i.e., water, electricity;
– staff costs;
– maintenance costs;
– other costs, i.e., storage of sediments.

Based on these data, the required investment, as well as running costs, can be estimated. Together with expected quantities of treated ballast water per year, these data can be used to estimate the unit costs of the ballast water treatment and estimate project cash flow during the reception facility life cycle.

After estimating the financial requirements for selected ballast water reception facilities, a preliminary hazard analysis may be carried out. The preliminary hazard analysis is a semi-quantitative method, aiming to identify potential hazards the port is exposed to if different options are selected. The options under consideration should include different designs of the ballast water reception facilities and may include implementing different contingency measures as alternatives to ballast water reception facilities. A port authority may use the most probable scenarios and their financial outcomes as criteria to implement different contingency measures.

Finally, the legal feasibility may be checked. The goal of the legal feasibility is to estimate the legal implications of the ballast water reception facilities (including different options) and their operations. Also, it should investigate legal barriers that may obstruct the timely procurement and operations of the ballast water reception facility. The important part of the legal feasibility is examining the planned BWMS regarding national environmental requirements, either as a part of the legal feasibility study or as a separate environmental study. Depending on the

national requirements and characteristics of the treatment method, the environmental impact assessment may be needed.

Based on previously collected data and assessments, it is possible to reach informed decisions on the appropriateness of the considered ballast water reception facility. Moreover, the overall rate of return may be estimated, indicating the applicable business model (as a profit-oriented venture or as a public service). Finally, if identified hazards are low and investments quite high, a decision not to develop the ballast water reception facility may be adopted.

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6 Optimising Port Reception Facilities

Selecting the most suitable port reception facility is not a simple task. Variability of different factors is significant, especially regarding the existing infrastructure, the distance among berths or terminals, and traffic volumes. An effective solution for one port could be completely ineffective and expensive for another.

Although the economic viability study could provide decision-makers with the necessary information, a tailor-made computer simulation can obtain more realistic information about future operations in real environments (Pereira and Brinati 2012). Simulations more accurately estimate information on the reception facility efficacy under different port conditions and loads (Maglić et al. 2015), such as average working time, number of conflicting requests, and ships' delays.

As for any simulation, the quality of outputs depends mainly on the quality of the input data, i.e., the port-, traffic-, and ballast discharging-related information. The basic input data for the simulations are the following:

Port capacity. A number representing single berths available in the port or a maximum number of ships that can be berthed in the port at the same time.
Relative position of the berths/terminals. Positions of berths and terminals are needed to derive distances among berths/terminals using shore routes (for land-based BWM solutions, i.e., trucks) and sea routes (for barge-based solutions).
Ships discharging ballast water. The statistical distributions of ships discharging ballast water, the frequency of discharging and the discharged ballast volume, cargo quantities loaded or unloaded in a certain timestamp for each ship type calling in the port. The ballast water discharge history should be based on a sufficiently long time series of data (at least 3 years). The standard ballast water reports are a good source of these data.
Port dynamics. Port dynamics include various data for each terminal, mostly statistical distributions derived from measurements or other sources, such as manoeuvring times (from pilot station/anchorage to terminal and vice versa) and port times (the time the ship is berthed alongside, based on average loading/unloading rates).
Proportion of ships requesting port BWM services. Same data as above but related only to the ships not complying with the BWM Convention. If data are not available, then they must be estimated. Information collected by Port State Control Officers may help in this respect.
Specification of the selected ballast water reception system. Data include the BWMS capacities and limitations (if any) and the availability and speed of transport units (for trucks, ships, or barges) for mobile solutions. The service is assumed to be assigned to ships

on the ‘first come-first served’ principle, although it may not always be the case.

The basic output of the simulations should provide at least:

– total number and arrival frequency of ships discharging ballast water per berth/terminal in a given time;
– a total volume of discharged ballast water per berth/terminal in a given time;
– estimated volumes of collected ballast water using a port-based BWMS;
– the utilisation of a port-based BWMS, i.e., the frequency and duration of operations;
– ships’ delays due to unavailability of the selected port-based BWMS.

The simulation can be developed using off-the-shelf software packages available on the market. The simulation run must include the warm-up period (we recommend at least 3 years) to provide stable results. The simulation may be relatively simple, in case of the port with just one or two berths and one or two ship types, or quite complex, if it covers a large port, with numerous terminals and berths, and all kinds of ship types and sizes.

Simulations can be run with several different scenarios. By doing so, the system’s performance can be better estimated, giving better insights into the system’s limitations. Even more, it may be run with different port solutions (barge vs truck vs land-based) and different loading situations, thus being an effective tool to compare the most appropriate port-based BWMS.

Finally, the simulation can provide an overview of effectiveness and estimate the possible overall expenses of operations (including staff working time and energy consumption).

7 Conclusions

The BWM Convention presumes that BWM will be carried out onboard ships by appropriate practice or shipboard equipment, i.e., BWMS.

Yet, there are circumstances when ballast water to be discharged cannot be treated in accordance with BWM Convention requirements by using shipboard equipment. In such cases, the port-based ballast water reception facility may provide an effective solution.

Port-based solutions include land-based, barge-based, and mobile truck-based BWMS and all use practically the same treatment technology commonly used onboard ships. Each solution has certain advantages and disadvantages, more or less emphasised depending on the port configuration, traffic volumes, required ballast water capacities, etc.

Nevertheless, presently two main disadvantages are preventing wider use of port-based solutions. The first one is of technical nature: most ships do not have arrangements to discharge ballast water to port-based ballast water reception facilities, thus significantly reducing the feasibility of the port-based solutions. In addition, there is no standardised technical connection between such a facility and the ship. We recommend that such a standardised connection be agreed to enable the further development and use of such reception facilities. The second one is related to the economic viability; due to the limited demand and relatively high capital and operational costs, the profitability of such a service is uncertain.

Due to these characteristics, the decision to implement a port-based system should be based on a thorough analysis of data and modelling port dynamics, preferably estimating the system’s efficiency in different circumstances using numerical simulations. In the case of ports without ballast

water reception facilities, the responsible authorities should consider other contingency measures in case of non-compliant ballast water to be managed.

Last but not least, decision-makers should respect the fact that port-based BWMS may minimise the risk of introducing harmful aquatic organisms and pathogens compared to the ‘do nothing’ option when an onboard BWMS fails.

Acknowledgements

The findings and conclusions presented here are in significant part made as a part of the research activities during the BALMAS project, the EU supported project produced with the financial assistance of the IPA Adriatic Cross-Border Cooperation Programme.

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Footnotes

1 The Convention has been adopted on 13 February 2004. It entered into force on 8 September 2017.

2 Such approach is preferred by Caribbean countries. See BWM.3/Circ.2 Communication received from the Regional Activity Centre/Regional Marine Pollution Emergency, Information and Training Centre – Wider Caribbean Region (RAC/REMPEITC-Caribe), 5 June 2018.

3 For example, USCG Policy Letter 18-02 Guidelines for Evaluating Potential Courses of Action When a Vessel Bound for a Port in the United States has an Inoperable Ballast Water Management (BWM) System contains guidelines for vessels and Coast Guard personnel in the event of a failure of a ship's ballast water treatment plant.

4 The idea, involving ships used as a storage for ballast water and entitled BWTBoat, is elaborated by Patil (2019), and strongly supported by Indian interest.

5 For example, the loading terminal at Scapa Flow, UK, has storage tanks (159,000 m^3) for oily waters occupying approximately 40,000 m^2, while treatment facility occupies another 20,000 m^2.

6 It is estimated that a mobile land-based system can serve ports up to 50 km of road distance from the base port with no significant delays, except in cases of concurrent requests.

7 https://www.bawat.com/mobile-bwms/mobile-bwms/. Last accessed in March 2024.

8 https://www.marinelog.com/news/mobile-ballast-water-treatment-system-available-in-port-of-hamburg/. Last time accessed March 2024.

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M. David, S. Gollasch (eds.), *Global Maritime Transport and Ballast Water Management*, Invading Nature - Springer Series in Invasion Ecology 16
https://doi.org/10.1007/978-3-031-48193-2_8

Ballast Tank Sediment: A Neglected Subject Which Requires Management

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Abstract
Sediment releases from ballast tanks are of concern to the environment as they may contain chemical contaminants

and living organisms accumulated since the last docking visit of the vessel. This is one of the reasons why the International Convention for the Control and Management of Ships' Ballast Water and Sediments, 2004 (IMO 2004) (BWM Convention) also addresses sediment. IMO further developed guidelines for sediment reception facilities (Guidelines G1) and adopted Guidelines G12 to minimize the uptake and undesirable entrapment of sediments, to facilitate removal of sediments and provide safe access to allow for sediment removal. In essence, when a port State offers services where sediment is removed from the tanks, adequate facilities for the reception of sediments should be provided in ports and terminals where the cleaning and repairing of ballast tanks occurs. Further, each State shall report to the Organization on the availability and location of any reception facilities for the environmentally safe disposal of sediments. In addition, the BWM Convention gives detailed requirements for sediment management for vessels. This means that vessels shall remove and dispose sediments from ballast tanks according to their Ballast Water Management Plans in which detailed procedures for the disposal of sediments on shore shall be provided. With this, appropriate sediment collection and disposal in shipyards and ports becomes now a new challenge. We have conducted studies on the volumes and content of sediment, and will describe how to best approach this issue. In addition, we present the current sediment management situation in Turkey as a case study of a country with a larger number of dockyards located along three different seas.

Keywords Sediment – Ballast tank – Chemical contamination – Reception facility – Turkey

1 Introduction

The International Maritime Organization (IMO) BWM Convention entered into force in September 2017 to reduce one of the greatest negative influences humans have caused to the world's oceans, i.e., species transfers beyond their natural occurrence limits. When the BWM Convention is referred to, the main focus is almost always on ballast water. However, from the title of this Convention it is clear that also sediment needs to be addressed as the full Convention title reads: International Convention for the Control and Management of Ships' Ballast Water *and Sediments* (IMO 2004).

Sediment discharges from ballast tanks are of concern as they may contain living organisms which may have accumulated since the last docking visit of the vessel. In addition, chemical contaminants may have accumulated in the sediment, which may also cause unwanted impacts when released into the environment (e.g., Hamer et al. 1999; Gollasch et al. 2002, 2015; Ding et al. 2013; Werschkun et al. 2014; Culin and Mustac 2015; Maglić et al. 2016).

In contrast to studies on ballast water, sediment releases from ballast tanks and their consequences have attracted much less research attention over the past decades (Gollasch and David 2018, 2019). However, it is obvious that when ballast water is taken on board, re-suspended sediment and the associated (benthic) organisms, including cysts and other resting stages, are also taken on board (Bailey et al. 2005; Dong et al. 2021). This is especially the case in shallow areas with high sediment load in the water, e.g., mainly in rivers and estuaries, and in ports when under keel clearance is small. Inside a ballast tank the sediment settles to the bottom and begins to accumulate through several ballasting operations.

BWM Convention reads in Regulation B-5 that all ships shall remove and dispose of sediments from spaces

designated to carry ballast water in accordance with the provisions of the ship's ballast water management plan. To support the sediment aspect of the BWM Convention, IMO has developed two guidelines: (a) Guidelines G1 for sediment reception facilities (IMO 2006a) and (b) Guidelines G12 for sediment control on ships (IMO 2006b). G1 gives guidance how land-based sediment reception facilities should be set up, with the key principle that the sediment should not re-enter the aquatic environment. G12 provides recommendations how the sediment uptake may be minimized and how sediment entrapment in a ballast tank can be reduced. It gives further recommendations to facilitate removal of sediments, and provide safe access to allow for sediment removal.

This chapter provides information on the amount and type of sediment accumulation inside ballast tanks and the importance of sediment to facilitate species movements. Further, we present the ballast sediment management situation in Turkey as a case study because research projects on this subject were completed recently and also Turkey has a larger number of dockyards along three different seas, which add challenges to the originally complex subject.

2 Amount and Type of Sediment

Inside ballast tanks the sediment settles to the tank bottom and begins to accumulate (Gollasch and David, 2018, 2019). The dimension of accumulated sediment in a tank is influenced primarily by (a) the amount of suspended matter in the water where a vessel is ballasting, (b) the vessels ballast management practices, (c) the design and type of ballast tanks and (d) the time since the tanks were cleaned last during a dry-dock visit (Gollasch 1996; Lucas et al. 1999; Hamer 2002; David et al. 2015; Maglić et al. 2016, 2019). These and other studies have shown that the

volumes of accumulated sediment vary considerably. This refers to differences within different locations of one ballast tank, between different ballast tanks of the same vessel and between different vessels. Bilgin Güney et al. (2018) determined the sediment accumulation in a ballast tank model. They showed that the strongest sediment accumulation rates occurred at the compartments, which are next to the central continuous girder around the mid-part of the tank.

When tank sampling is done by entering into the tank it has to be ensured that the tank is properly ventilated before the sampling team enters (Fig. 1). This requirement was in addition to the required onboard tank entry procedures, which implement IMO's International Safety Management (ISM) Code. Later, samples were also taken near the manhole without breathing gear (Fig. 2).

Fig. 1 Self-containing breathing apparatus for tank inspections (Photo credit: Stephan Gollasch)

Fig. 2 Tank sediment sampling via manholes (Photo credit: Stephan Gollasch)

Sediment dimensions found during research studies varied from a thickness of less than 1 cm, which was predominantly found (Hallegraeff and Bolch 1991, 1992; Locke et al. 1991, 1993; Gollasch 1996; Bailey et al. 2005; Prange & Pereira 2013; Maglić et al. 2016), to layers of more than 50 cm thick (Gollasch 1996). This means that tens or even hundreds of tons of sediment may accumulate in the ballast tanks of larger vessels (Clarke and Haskins 1993).

The sediment type also varied between vessels (Wittling 1999), but most sediment found was silt or fine mud with a mean particle size of <20 µm (Gollasch 1996; Wittling 1999; Hamer 2002; Johengen et al. 2005; Radziejewska et al. 2006; Gruska et al. 2013). Rarely also larger particle sediment was found (Gollasch 1996; Wittling 1999; Zec et al. 2015) (Figs. 3 and 4).

Fig. 3 Larger particle sediment sampled in a ballast tank (Photo credit: Stephan Gollasch)

Fig. 4 Sampling of fine sediment in a ballast tank (Photo credit: Stephan Gollasch)

In another study, larger particles were found in the sediment and it was assumed that they originated from the deterioration of tank plates and tank coating residues (Maglić et al. 2016) (Fig. 5). Also, unexpected objects were found when entering a ballast tank (Fig. 6).

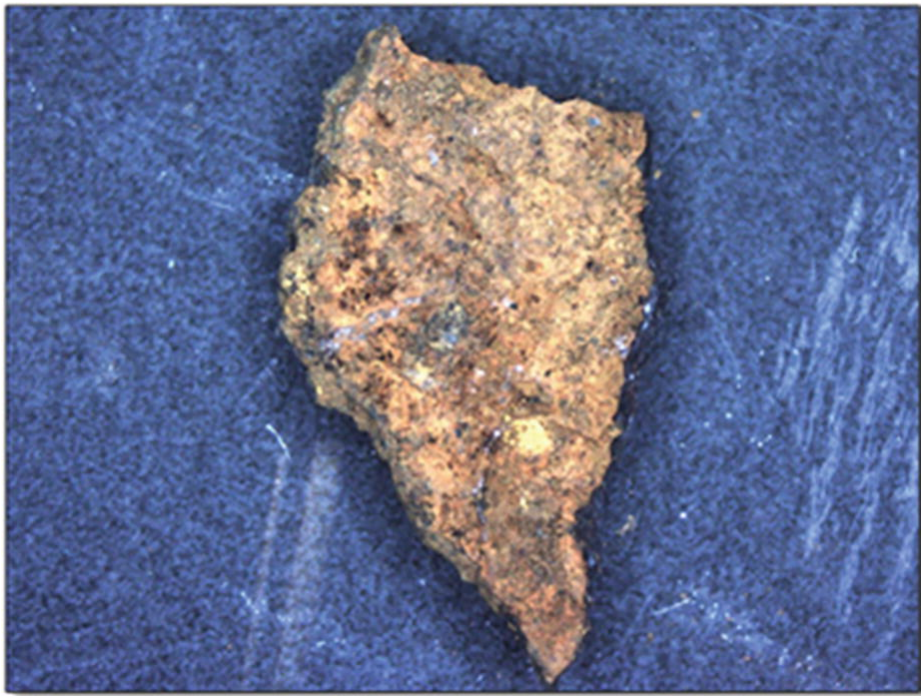

Fig. 5 Small piece of raw sediment (size of a few micrometres) showing small pieces of paint and corroded steel (Photo credit: Damir Zec)

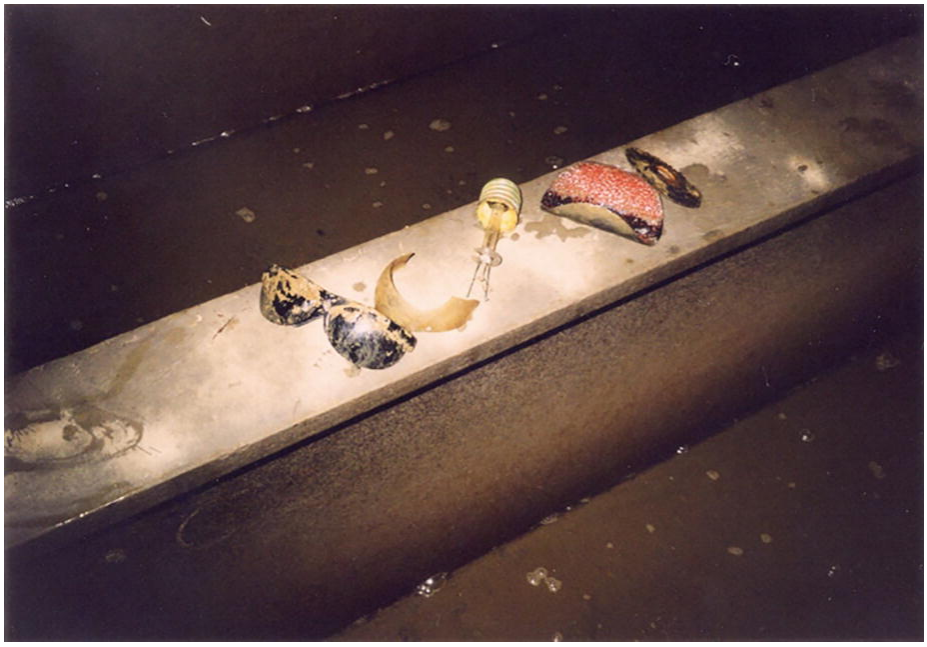

Fig. 6 Unexpected objects collected at the bottom of a ballast tank during sediment sampling (Photo credit: Stephan Gollasch)

The water content of the sediment is generally relatively high, at a level of 60%, and the content of organic

substance/matter is relatively low, while the inorganic content is comparatively high (Olgun and Basar 2016).

It was observed that sediments in ballast tanks gradually harden so that it becomes denser under water pressure. This process of hardening is due to repelling of ballast water. Such hardened sediments are usually difficult to remove and require intense manual work (Maglić et al. 2019).

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3 Species in Ballast Tank Sediment

In contrast to studies on ballast water, biological studies on sediment from ballast tanks were much less in the research focus over the past decades. However, it is clear that when a vessel takes on ballast water, especially in shallow areas, re-suspended sediment and the associated organisms are also taken on board.

Sediment sampling studies revealed the presence of bacteria, viruses, phytoplankton, adult and juvenile stages of numerous invertebrates as well as fish. Next to ballast water, the second highest numbers of species found in ballast water tanks were recorded from tank sediments (Gollasch and David 2019). In one of the first sediment sampling studies the number of species in sediment was approximately of the same level as those species found in ballast water samples. The dominating taxa were Bivalvia, Cirripedia, Gastropoda and Cladocera. Up to 26 different species were found in a single sediment sample, including also Decapoda and fish (Gollasch 1996; Fig. 7) and Gruszka et al. (2013) found even 29 different species in the sediment from a single tank. When summarizing the European ballast tank sediment studies completed until 2001 more than 125 species were found (Gollasch et al. 2002) and in sediment sampled of vessels arriving in the North American Great Lakes a cumulative total of 160 species were identified (Bailey et al. 2007), which was

followed by a study in the Port of Vancouver, Canada (Sutherland and Levings 2013), with similar findings. In addition, bacteria and viruses are known to occur associated with ballast tank sediments (Drake et al. 2007; Lv et al. 2018).

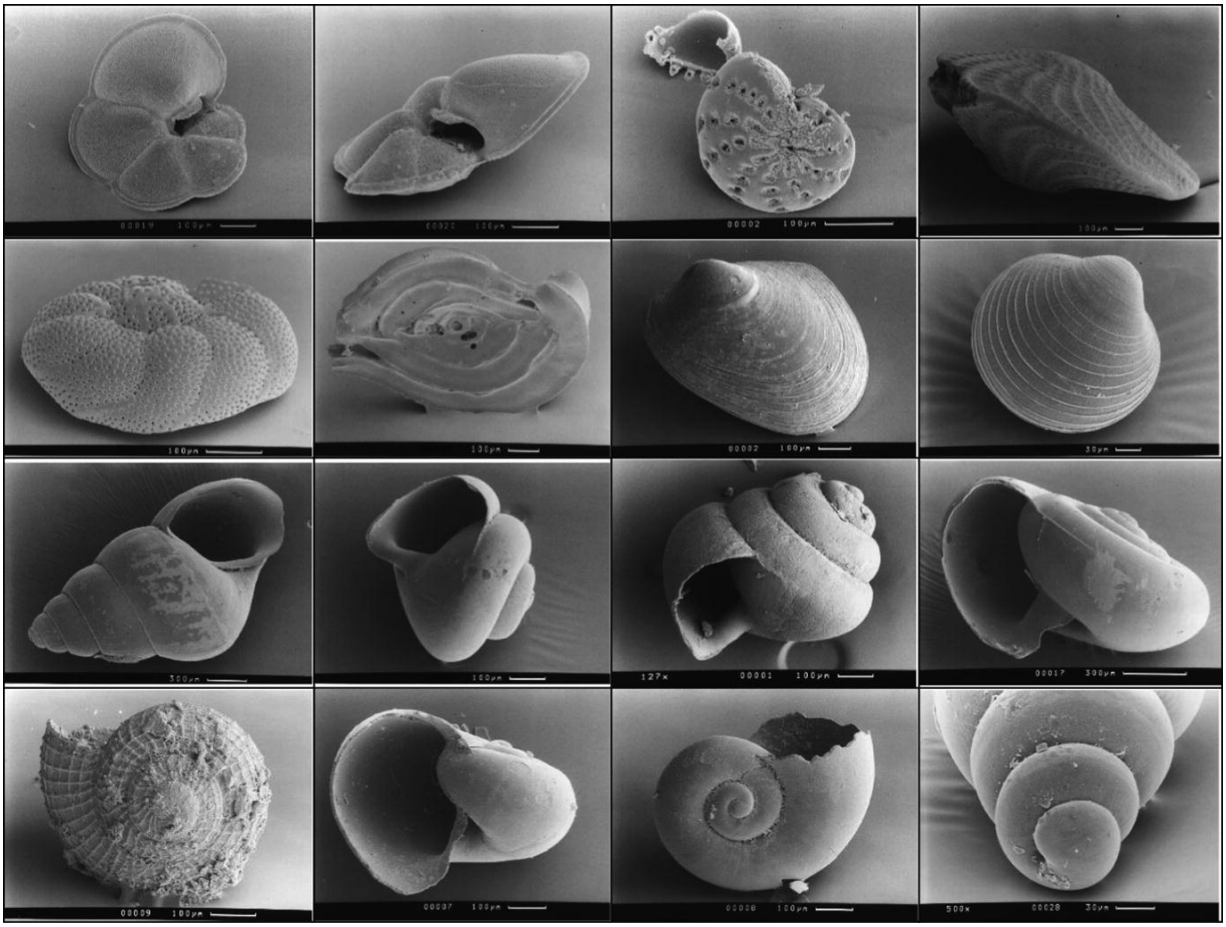

Fig. 7 Electron microscopy photographs of selected hard-shelled organisms found in ballast tank sediments (Photo credit: Stephan Gollasch)

Regarding organism numbers it was found in a recent sediment study that meiobenthic organisms, dominated by nematodes and foraminifers, occurred in the sediment at abundances of 14–107,800 ind./dm^3 sediment. The macrobenthic organisms were predominantly oligochaetes, polychaetes and larger nematodes. Their abundances ranged from 0.3–7.6 ind./dm^3 sediment (Gruszka et al. 2013).

In other studies, the occurrence of various resting stages, i.e., diapausing eggs, cysts and phytoplankton spores, was documented (Hallegraeff and Bolch 1992; Hamer et al. 2001; Radziejewska et al. 2006; Villac et al. 2013; Shang et al. 2019; Zhang et al. 2020; Dong et al. 2021). Some of these resting stages may be long-lived and are capable of surviving for a few years and some species are even capable of germination after 9 years (Lewis et al. 1999; Gray and MacIsaac 2010).

Bailey et al. (2003) found 500–430,000 diapausing eggs per square metre (predominantly rotifers, cladocerans and calanoid copepods) and these numbers are typically one order of magnitude lower than densities observed in nature. In another study 80–850 cysts were found per gram of sediment (Johengen et al. 2005).

Of additional concern is the occurrence of dinoflagellates of potentially toxic species in tank sediments, which has been studied in most detail in several projects (e.g., Hallegraeff and Bolch 1991, 1992; Kelly 1993; Macdonald and Davidson 1997; Hamer et al. 1998, 2000, 2001; Harvey et al. 1999; Wittling 1999; Lenz et al. 2000; Gollasch et al. 2002; Bailey et al. 2005; Duggan et al. 2005; Wonham et al. 2005; Kang et al. 2010; Briski et al. 2010, 2011; Casas-Monroy et al. 2011; Gruszka et al. 2013; Branstator et al. 2015). These cysts are remarkably tolerant to adverse abiotic conditions, e.g., heat, salinity, UV radiation (Hallegraeff 1998; Hallegraeff and Gollasch 2006; Gregg and Hallegraeff 2007). A study in England and Wales found dinoflagellate cysts in 69% of sediment samples and again identified cysts of potentially toxic or non-native species (Hamer et al. 2001). This makes it clear that the sediment treatment to inactivate these cysts, thereby avoiding the unwanted negative impacts, is not an easy task (Hallegraeff 1998; Hallegraeff and Gollasch 2006; Gregg and Hallegraeff 2007).

Studying the sediment pore water, virus-like particle concentrations varied between 10^7 and 10^{11}/ml and bacteria concentrations ranged from 10^4 to 10^8/ml. Within the diverse taxa determined also microbial pathogens were found, including *Vibrio cholerae* (Johengen et al. 2005). In a more recent study Lv et al. (2017) found in a genetic study a significant higher diversity of bacteria in tank sediments compared to the ballast water. The high contents of sulphate-reducing bacteria and sulphur-oxidizing bacteria found in sediments indicate that bacteriological corrosion might occur in ballast tanks. Further, antibiotic resistance genes and human bacterial pathogens were found in ballast tank sediments (Lv et al. 2018).

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4 Chemicals in the Sediment

Sediment releases from ballast tanks are of concern to the environment as they may also contain chemical contaminants accumulated since the last docking visit of the vessel (Ding et al. 2013; Werschkun et al. 2014; Culin and Mustac 2015; Su et al. 2017). The most important sources of the chemicals in sediment are paints used to protect tank walls from corrosive processes (IACS 2015). Over time the strength of the paint decreases and small pieces of paint are mixing with sediment (Fig. 5). The amount of these chemicals released may negatively impact on the recipient environments by chemical pollution (IACS 2015). Su et al. (2017) found persistent organic pollutants (POPs) including polycyclic aromatic hydrocarbons (PAHs), polybrominated diphenyl ethers (PBDEs) and polychlorinated biphenyls (PCBs) in tank sediments. Tank sediment in general contained a higher amount of PBDEs compared to sediment sampled from the Port of Jiangyin City (China) where the vessel sampling study was conducted. They concluded that the release of sediment has

a high potential of posing risks to marine life should the tank sediments not be treated appropriately. Their results showed further that tank sediment POPs originated from multiple sources with atmospheric deposition being an important contributor. In addition, vessel activities including diesel exhaust and illegal oil discharge were identified as considerable contributors of some POPs content in tank sediments (Su et al. 2017). Other studies found considerable amounts of heavy metals in ballast tank sediment (Macdonald and Davidson 1997; Feng et al. 2016). Environmental risk assessments resulted in concentration of Zn, Pb and Cu categorized as highly toxic to aquatic organisms and the corrosion of ballast tanks played an important role (Feng et al. 2016). In consequence, some of the measured substance concentrations would categorize this material as hazardous landfill according to the 1999/31/EC Landfill of Waste Directive (Maglić et al. 2019).

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5 Sediment Removal

The frequency and timing of sediment removal depends on several factors, including the dimension of sediment build up, vessel's trading pattern, availability of reception facilities, work load of the vessel's crew and safety issues (David et al. 2015).

Sediment from ballast water tanks is removed for different reasons, including (a) the amount of sediments negatively influences the economic efficiency of the ship, (b) ballast tanks need to be surveyed within regular maintenance processes, (c) ballast tanks have to be repaired and/or (d) the suction bell of the ballast water system in the ballast tank is obstructed so that pumping of ballast water is difficult or impossible (Maglić et al. 2019).

As a recent study revealed, sediments are usually removed from ballast tanks when the vessels are in a

dockyard (Gollasch and David 2016) and this is usually done in two ways. In routine operations, the sediment is predominantly washed out of the tanks by high pressure watering and the sediment water solution is drained from the tanks through tank bottom screws (Fig. 8). When using the tank washing method, sediment drained out of the tank is not collected. The sediment water solution usually runs from the dockyard into the sea. In addition, tank sediment may be extracted mechanically by using a shovel and buckets, which is a tedious and demanding task. This is because ballast tanks are designed with confined spaces and inner structures, e.g., frames and longitudinals (Bilgin Güney et al. 2018). Further, the working area to be cleaned lacks natural light and ventilation. As a result, the work is labour intensive and expensive. Frequently, the workers need to enter ballast tanks to reach the tank bottom and other areas with entrapped sediment for manual sediment removal. If the sediment is hardened its structure needs to be broken. Under certain circumstances vacuum cleaning equipment may be used to extract the sediment from a tank. In this case the sediment is collected in containers. In any case, during manual sediment collection, the workers are exposed to a possible human health risk because of the chemical and biological content of the sediment. Therefore, personal protective equipment should be worn (Maglić et al. 2019).

Fig. 8 Draining double bottom tanks of water and suspended sediment in a dockyard through drain holes (Photo credit: Piotr Gruszka, Gdynia Maritime University, Maritime Institute, Gdańsk, Poland)

Occasionally vessel crews clean tanks while the vessel is in navigation. When this is done in navigation the sediment is either disposed over board or delivered to a waste reception facility in the next port of call (Zec et al. 2015; Maglić et al. 2019). However, according to U.S. EPA (2013) most sediment removal occurs in shipyards.

In common practice vessels are dry-docked every 2½ years for an intermediate survey of the hull structure, and every 5 years for a more detailed class renewal survey of the hull structure integrity, which would include a hull thickness measurement. For both surveys tanks are opened, and ballast water is drained from the tanks. If

there is very little accumulation of sediment, this would not necessarily be removed. However, when more sediment accumulated, and to enable the hull thickness measurement, tank cleaning is conducted with complete removal of sediment.

As already stated above, the volume of sediment that would accumulate very much depends in which ports a vessel is ballasting and the volume of suspended matter there. Ports in rivers and estuaries are usually those with most suspended matter. It is estimated that in general 1–2 cm of sediment would accumulate in a tank per year, and for rough calculations, 1% of the ballast tank volume would be filled with sediment per year (Gollasch and David 2016).

As an example, Prange and Pereira (2013) calculated the maximum amount and weight of tank sediment for a Panamax-type bulk carrier (LOA of 220 m, breadth 32.20 m). Such a vessel typically contains ballast tanks of a joint area of ca. 150 m in length by ca. 30 m in width, which totals to ca. 4500 m^2. An assumed sediment layer of 0.10 m over the entire tank bottom would result in a volume of ca. 450 m^3. When considering the sediment weight, which mostly depends on the water content, the calculation resulted in ca. 675 tons sediment weight for this vessel. However, they also stated that such a sediment build-up is relatively rare. For most mid-sized ocean-going vessels, the weight of accumulated sediments typically varies between 10 and 15 tons (Prange and Pereira 2013).

The amount of sediment to be handled is not well documented and the different dockyards have different approaches to handle sediment (Zec et al. 2015). Some deal with sediment separately, others release the sediment in the dock and collect all material from the bottom of the dock including material sand blasted from the hull, sediment from tanks, material from sea chests, etc.

Common practice is that the dockyards have hired subcontractors to deal with the sediment disposal on land and this is done according to the contamination level of the material following national legislations.

Should sediment be contaminated it should be disposed in properly isolated facilities to ensure that, e.g., heavy metals cannot drain into the ground water. In most facilities de-watering of sediment before land disposal occurs and is conducted by gravity separation of sediment and water.

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6 Avoidance of Sediment Accumulation

As shown during the studies mentioned above a substantial amount of sediment may accumulate in ballast tanks. This is disadvantageous because this sediment cannot be pumped out of the ballast water tank so that its weight reduces the cargo capacity of a vessel. To address this IMO has developed Guidelines G12 (IMO 2006b), to make naval architects considering to redesign ballast tanks. The benefits of new design concepts to reduce sediment accumulation are that this will likely result in good sediment removal while deballasting, with reduced retention of sediment in the tanks. At best this would result in situations where there is no need for sediment removal by other means.

Guidelines G12 provide many recommendations how sediment entrapment in a ballast tank may be reduced, which in particular refers to internal structures of ballast tanks. Subjects to consider when designing ballast tanks include:

- avoidance of horizontal surfaces wherever possible;
- where face bar stiffeners are fitted to longitudinals, these stiffeners may be fitted below the horizontal surfaces to

aid drain off from the stiffeners;

- create in-tank water flows (e.g., by pump or gravitational forces) to wash horizontal surfaces so that settled sediment is re-suspended;
- when horizontal stringers or webs are needed, install drainage holes as large as possible to enable rapid flow of water off them when the water level in the tank falls;
- internal girders, longitudinals, stiffeners, intercostals and floors should have extra drain holes to enable water flow with minimal restriction during discharge and stripping operations;
- bulkheads arrangements should enable to prevent the formation of stagnant water pools or sediment traps;
- scallops should be located at the joints of the inner bottom (tank top) longitudinals or intercostals and floors to enable good airflow for drying out an empty ballast tank;
- pipeline systems should be designed to create powerful disturbance of the water inside a tank, which should result in the re-suspension of sediment;
- water flow characteristics in ballast water tanks should be studied (e.g., by computational fluid dynamics) to design internal tank structures, which provide effective sediment flushing; and
- facilitate the installation of in-tank ballast water suction points on each side of the tank.

Some of these subjects were considered and naval architects developed sediment accumulation avoidance methods, which include the addition and enlargement of existing holes (i.e., scallops) between transversal walls inside ballast tanks. These holes should also be positioned as much to the bottom of the ballast tanks as possible. It was further suggested to install water jets for the stirring to avoid the accumulation of sediments on the tank bottoms. They also recommended installing more than one suction point in a single ballast water tank to increase the

sediment extraction rate during the ballast water pumping process (Prange and Pereira 2013; Bilgin Güney et al. 2018).

In addition to modifying the tank design, it is also advisable to avoid ballast water operations in waters with high sediment content, as practicable. IMO has addressed this in its Guidelines G4 (IMO 2005), which recommends to, when loading ballast water, avoid the uptake of sediments. Therefore, the uptake of ballast water should be minimized or, where practicable, avoided in areas:

- with very shallow waters;
- where propellers may stir up sediment;
- where a tidal stream is known to be more turbid; or
- where tidal flushing is known to be poor.

Further, it was expected that sediment accumulation in ballast tanks will decrease when ballast water management systems (BWMS) begin to be used routinely. It is correct that today almost all BWMS use mechanical separation of larger particles, such as filters and/or hydrocyclones. These technologies predominantly remove larger organisms but at the same time larger sediment particles are also extracted. Mesh sizes of the most commonly used filters in BWMS are usually between 40 and 50 µm. The use of these mesh sizes results only in the removal of larger sediment particles but will not prevent the build-up of fine silt and clay in the tanks so that the problem of sediment accumulation continues although BWMS are used. Johengen et al. (2005) calculated that a filter with a mesh size of 50 µm would only have reduced the sediment accumulation in tanks by ca. 10%.

In another study a pneumatic cleaning system of the centre ballast tank girder was designed to re-suspend sediment with the aim to increase the sediment discharge from the tank. In a test the system reduced the total in-tank sediment deposition of a model tank up to 45%. Therefore,

operating such a system before deballasting operations are started would result in a reduction of sediment accumulation thereby reducing cumulative deadweight loss (Bilgin Güney et al. 2020).

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7 Sediment Management in Turkey

In a recent study conducted for Turkish shipyards, the methods for tank sediments management in compliance with BWM Convention and national waste management regulations were evaluated considering the (a) possible amount and physical as well as chemical characteristics of the sediment to be disposed, (b) effects the sediment will/may have on the environment and human health and (c) availability and costs of sediment disposal or possible re-use methods for the sediment (Olgun and Başar 2016).

Turkey has a comprehensive shipyard industry. By the end of 2017, a total of 77 shipyards (3 military and 74 industrial) existed along the Turkish coasts (MoE 2017), the majority of these shipyards are located in the Marmara and Black seas region. Most shipyards providing maintenance and repair services to vessels are located in the Tuzla and Yalova shipyard areas in the Marmara Sea region. Therefore, an infrastructure related to sediment reception facilities is required particularly in the Marmara Sea region, especially as Turkey is a Party to the BWM Convention, hence requirements have now to be implemented.

According to the information provided in interviews made with the Environment Coordination Unit of GİSAS Ship Building Industry Co. during project studies, in the Tuzla shipyards region with approximately 20 repair shipyards, each shipyard cleans in average ballast tanks of two vessels on a monthly basis. This work generates approximately 400 tonnes of ballast tank sediment waste per month. Currently, wastes from vessels in shipyards and

ports are disposed of in accordance with national environmental and waste management regulations. The implemented national practices are that wastes are classified and disposed according to requirements of the Waste Management Regulation (WMR) 2015. The criteria to enable using the tank sediment as landfill are outlined in Regulation on Landfilling of Wastes (RoLW) 2010. Both regulations comply with EU Directives (i.e., 2008/98/EC Waste Framework Directive and 1999/31/EC Landfill of Waste Directive).

Before a decision can be taken whether or not tank sediments may be disposed on land or will be re-used otherwise, the potential hazards to the environment and human health, the physical properties as well as chemical and biological content of the sediment has to be evaluated. The result of such an evaluation leads to identify the most appropriate and cost-effective technical solutions, which may be different for different types of sediment, taking into account the grain size composition and chemical contamination. In sediment characterization studies, the analyses specified in WMR and RoLW were carried out on sediment samples taken from ballast tanks to determine its class as a waste, its landfill disposal potential and whether or not it was suitable for re-use at all. Tests and analyses were performed for five sediment samples and these tests were done according to principles of RoLW to determine (1) the hazard level of the tank sediment wastes, (2) the particle size distribution, (3) the physicochemical analyses, (4) the organic content, (5) the inorganic content and (6) to conduct an ecologic toxicity test.

The results of the detailed sediment analysis showed that the concentration of organic and inorganic pollutants is below the hazardous waste threshold specified in WMR (Olgun and Başar 2016). Other important findings included low organic and high inorganic sediment content. The dominant grain size was between “fine sand” and “clay-silt

mixture” and the chloride (Cl) content exceeded in some cases the limit value in RoLW. Chloride is the most abundant ion in marine water and it originates from the dissociation of salts, such as mainly sodium chloride or calcium chloride. In general, it can be expected that the chloride concentration in sediments of ships operating at marine waters will be higher as for those operating in freshwater environments. In addition, the content of solids was less than 50%, which is the limit value to enable landfill use, so that this sediment cannot be used as landfill material without de-watering. However, these results are based on a few sediment samples only and samples from other sediments may show different results (Olgun and Başar 2016). As the hazard properties of the sediment collected from vessels may differ from one vessel to another, either all wastes should be categorized as “possible hazardous waste” and be disposed accordingly or the disposal method will be decided once the necessary analyses were carried out. Categorizing all sediment as “possible hazardous waste” would help to avoid sediment analysis costs and delays due to sample processing time.

In Turkey, three sediment management options were agreed and they are selected according to the analysis results:

- Since the dominant particle size of ballast sediment is fine sand and clay-silt, the sediment is not suitable for use as fine aggregate in uses like concrete production, building highway infrastructures and supra-structures, soil and geotechnical uses, etc. Due to its high salinity, using tank sediments as land filling material is of high risk to the groundwater. Further, the annual amount of tank sediment would be too low to make the pre-treatments required for re-use economically feasible.
- Tank sediment had low calorific/energy value as the organic content and the oil-grease content was very low

compared to port water sediment. Therefore, the material is unsuitable for generating energy by burning/incinerating. Blending tank sediment with other material, which has higher calorific/energy value is not considered to be technically and economically feasible.
- The use of tank sediment as landfill is seen as the most suitable option for ultimate sediment disposal provided the necessary pre-treatment procedures, such as de-watering, de-salination by use of solidification/stabilization techniques and decontamination of chemicals, will be conducted (Olgun and Başar 2016).

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8 Recommendations for Best Sediment Management Practices and How to Proceed

The amount of the ballast tank sediments a port or shipyard may receive in a year is largely unclear. As also Maglić et al. (2019) noted, we observed that importance of sediment management is not fully understood, but that instruments have to be developed to harmonize procedures and requirements for temporary and/or permanent sediment reception facilities. Doing this, the recommendations given in the BWM Convention (IMO 2004) should be followed, which in essence means that when States develop sediment disposal management the following should be taken into consideration:

- Follow IMO guidelines when sediment management is implemented.
- Adequate facilities for the reception of sediments should be provided in ports and terminals where cleaning and repairing of ballast tanks occur.

- Reception facilities should operate in a way as to not cause undue delays to vessels and to provide environmentally safe sediment disposal.
- Provision for the safe disposal of sediments that does not impair or damage their environment, human health, property or resources of the sediment recipient or those of other States.
- Each Party to the BWM Convention shall notify IMO on the availability and location of sediment reception facilities as well as any inadequacy of such reception facilities.

Based on the current situation we further recommend to consider the following when developing sediment management practices:

- Develop and implement a national and/or regional dockyard framework procedure to ensure that all dockyards follow a similar sediment management strategy to efficiently enforce the BWM Convention in a harmonized approach.
- Ensure that workers who mechanically clean ballast tanks wear suitable personal protection equipment.
- Ensure that sediment removed from vessels and water extracted from sediment during a storage or treatment processes cannot re-enter the environment.
- Either categorizing all sediment as “possible hazardous waste” to avoid sediment analysis cost and delays due to sample processing time when planning sediment disposal. Alternatively dispose the sediment on land according to its contamination level.
- Consider re-use of uncontaminated or cleaned dry sediment as building material, filling material or for construction works.
- For increased compliance with sediment management requirements conduct an awareness campaign to explain the problems caused by introduced species and the

pollution risks of contaminants when sediment is released in the water. This campaign should address all stakeholders, including the workers in dockyards, vessel crews and operators of the sediment disposal facilities.

- Sanctions for cases when the sediment management requirements are not followed should be implemented to discourage violations.

When working towards appropriate sediment management in accordance with IMO requirements, a more detailed study of sediment discharge profiles in a dockyard (e.g., maximum volume per vessel, annual volume of sediment discharge to reception facilities) would be needed to estimate the capacity of such facilities.

With the BWM Convention in force now, each State has to report to the Organization on the availability and location of any reception facilities for the environmentally safe disposal of sediments. Further, as per the BWM Convention, detailed ballast water management plans need to be developed in which detailed procedures for the disposal of sediments on shore shall be provided. It would be also helpful for the shipping industry, and possibly also researchers, when IMO would make publicly available the collected information on existing sediment reception facilities, e.g., through GISIS (Global Integrated Shipping Information System).

Acknowledgements

We thank the funding sources of the ballast tank sediment studies referred to in this chapter, especially the EU IPA Project “BALMAS – Ballast Water Management System for Adriatic Sea Protection” (project code 1°STR/0005) and the sediment management studies carried out in the framework of the project “Technical Assistance for Capacity Building for Prevention of Marine Pollution Caused by Ship-Sourced Wastes (2015–2017)” by the TUBİTAK Marmara Research Center with the coordination of the Ministry of

Environment and Urbanization, Republic of Turkey. The project was supported by the EU-IPA programme and was conducted under the leadership of SWECO, Turkey.

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M. David, S. Gollasch (eds.), *Global Maritime Transport and Ballast Water Management*, Invading Nature - Springer Series in Invasion Ecology 16
https://doi.org/10.1007/978-3-031-48193-2_9

Databases to Support Different Ballast Water Management Tools

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Abstract
Ballast Water Management (BWM) is a complex process in which decision-making must be based on proven scientific evidence. For example, data is needed to make decisions on the granting of exemptions from BWM, to support an early warning system to inform seafarers about where ballasting should not be conducted due to the presence of harmful organisms, to control and eradicate invasive species and to measure the effectiveness of the BWM Convention in reducing the rate of new species introductions. To support different BWM tools, the data should be diverse and multifaceted, ranging from taxonomy and biological traits of introduced species to the limits of their ecological tolerance, vectors of introduction, history of invasions and actual geographic distribution, their impact on human health, economy and environment. Here we present examples of how existing databases can be used to provide the information needed for the implementation of the BWM Convention in general. Particular attention is paid to AquaNIS, an information system on aquatic non-indigenous and cryptogenic species that stores a wealth of data and is equipped with several useful tools aiding decision-making processes.

Keywords Ballast water – Management – Decision support – Invasive species – Information – Early warning system – AquaNIS

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1 Introduction

Information support is necessary in any decision-making process, especially in such a complex procedure as is the management of ships' ballast water (BWM). Ballast water is known to be a major vector to transfer Harmful Aquatic Organisms and Pathogens (HAOP) (IMO 2004), including potentially harmful Non-Indigenous Species (NIS), and Invasive Alien Species (IAS), i.e., those organisms, which may multiply in large numbers, spread and cause problems to human health, economies or environments (Olenin et al. 2011) as well as Cryptogenic Species (CS) (Carlton 1996), harmful native species and pathogens (David et al. 2013; Gollasch et al. 2015). Biological invasions attract increasing attention from policy makers, environmental protection authorities and scientists, and as a result the knowledge base on HAOP, NIS and IAS is continuously expanding (Gollasch 2002; Olenin et al. 2002, 2014).

With the BWM Convention in force and other legislative acts, such as EU Regulation on Invasive Alien Species (EU 2014), the demand for advanced, scientifically validated and up-to-date information support on NIS and other species is essential for, e.g., risk assessment and management. The European Alien Species Information Network (EASIN) was prepared to support this EU Regulation, however it does not provide any specific tools to support BWM. In the historical context, probably the first regional open information source worldwide, which appeared online already in 1997, was the Baltic Sea Alien Species Database (Olenin et al. 2002). This database contained information on NIS origin, introduction history, pathways and vectors. Currently, this database became part of a larger, new generation information system, dealing with aquatic NIS introduced to marine, brackish and coastal freshwater environments worldwide (AquaNIS) —The Information System on Aquatic Non-Indigenous and Cryptogenic Species (Olenin et al. 2014; AquaNIS 2021). AquaNIS stores and disseminates information on NIS

introduction histories, recipient regions, taxonomy, biological traits including plankton development stage, impacts, availability of molecular data and other relevant documented data. As a multifunctional system equipped with a flexible search engine and data comparative analyses tool, AquaNIS is increasingly being used for ballast water management. However, it should be noted that the IMO (2004) term HAOP also includes harmful native species that are not (yet) covered in AquaNIS.

BWM according to the BWM Convention may be required as a blanket or a selective approach (David and Gollasch 2015). A 'blanket approach', which means mandatory BWM for all ships, but may overburden shipping in a range of circumstances. An alternative is the 'selective approach' where BWM is required only for certain vessels. This approach should be based on a variety of information needs and procedural implications that lead to transparent and reliable BWM decisions. Such decision systems were developed for a variety of applications, especially in situations when large numbers of complex decisions have to be made in a consistent, transparent and defensible manner (David and Gollasch 2015). These systems are typically referred to as Decision Support Systems (DSS). DSS may comprise databases for data storage and retrieval, as well as may use an external database. The critical point is that database(s) have to contain all information needed by DSS for its functionality.

To implement a sound BWM process according to the selective BWM approach incorporated in the BWM Convention (David and Gollasch 2015), e.g., when assessing the risks posed by ballast water transfers to support decisions about required BWM (David et al. 2015; Gollasch et al. 2020) or vessel selection for Port State Control action (David et al. 2015), and in an Early Warning System (EWS) (Magaletti et al. 2018), the availability of reliable knowledge about species in the aquatic

environment is crucial. Databases are suitable tools to host such information and data, but they should be updated frequently to include records of newly introduced species, reflect changes in species taxonomy and reviewed regularly to eliminate possible mistakes (Olenin et al. 2014; Zenetos et al. 2018).

DSS process starts with communication and data input, continues with risk assessment, BWM decisions, vessel's action(s) and ends with monitoring and review processes (David and Gollasch 2015). Consequently, a database is needed to support the necessary information during the entire BWM-related decision processes, and the implementation of the BWM Convention requires multiple and diverse data to:

- document results of Port Baseline Surveys (PBS), which were conducted during the evaluation of exemptions from BWM requirements;
- support the decision-making on BWM exemptions;
- support EWS, which is set up to inform mariners where not to uptake ballast water due to the presence of critical species, such as toxic algal blooms;
- support species control and eradication programmes;
- measure the effectiveness of the BWM Convention to reduce HAOPs introductions by comparing newly recorded, ballast water-mediated introductions over time.

Below we present examples of how existing databases can be used to provide the information needed for the implementation of the BWM Convention in general.

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2 Documentation of Port Baseline Survey Results

PBS serve to determine the presence, abundance and distribution of NIS/CS and native HAOPs, which may have

been introduced by shipping, either in ballast water or attached to hulls, as well as by other vectors (Hewitt and Martin 2001; Awad et al. 2014; HELCOM/OSPAR 2020). PBSs may differ in scope, scale and complexity, ranging from rapid assessment surveys of target species to more comprehensive full-scale taxonomic investigations (Olenin et al. 2016a, b). In many areas, such surveys will be the only source of reliable information on the presence of taxa under concern and thus the main basis for risk assessments and administrative decisions. The systematic archiving of biological records, particularly of NIS and native HAOP not only for future reference but also for the benefit of the international community engaged in preventative programmes is of crucial importance (Awad et al. 2014). NIS and HAOP monitoring is of little use if the knowledge gained has not been gathered through reliable sampling protocols, is timely and can be directly used by researchers and management (Olenin et al. 2011, 2014). Consequently, data obtained from monitoring and surveys should be quality-assured and available for exchange between researchers and managers worldwide (Olenin et al. 2016a, b). This becomes possible through a centralised information system that integrates data from PBSs and a wide range of other NIS monitoring programmes (Fig. 1).

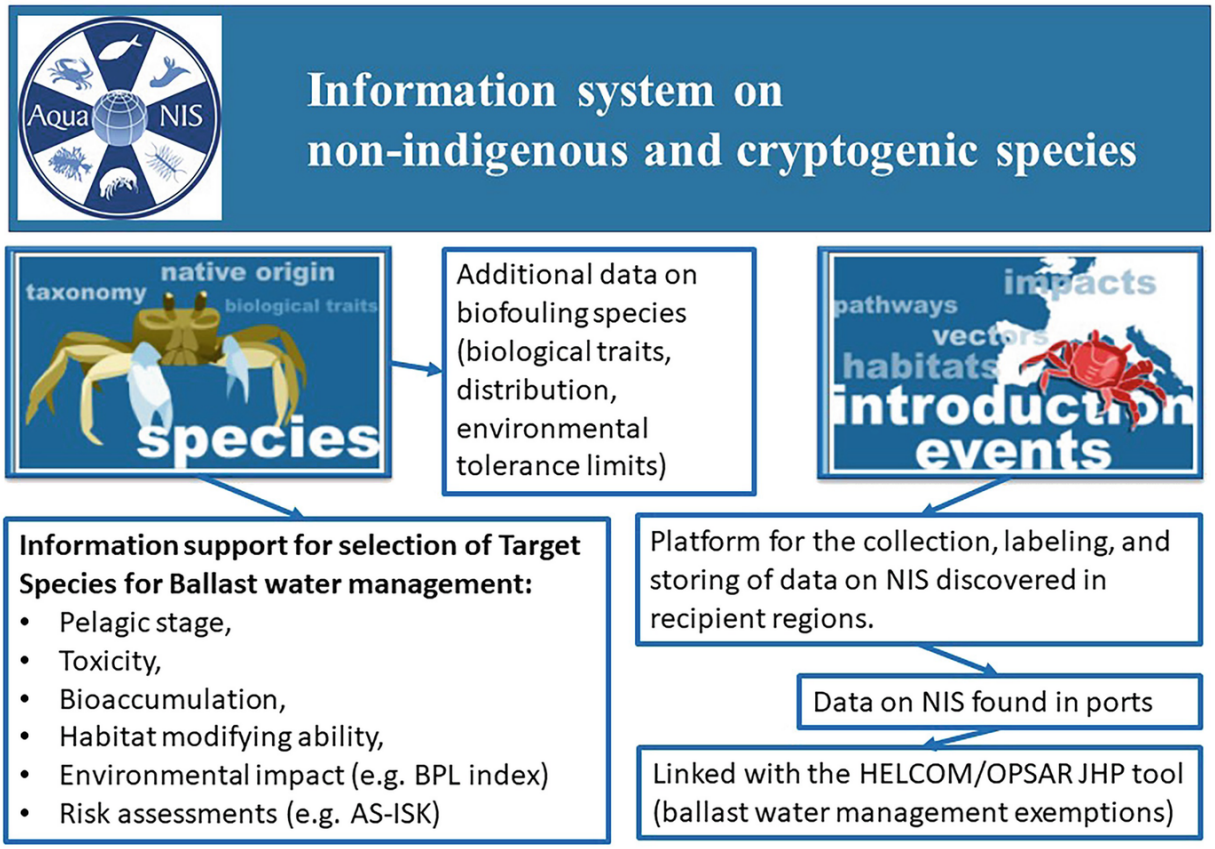
Aqua NIS
Information system on non-indigenous and cryptogenic species
native origin
taxonomy
biological traits
species
Additional data on biofouling species (biological traits, distribution, environmental tolerance limits)
impacts
pathways
vectors
habitats
introduction events
Information support for selection of Target Species for Ballast water management:
• Pelagic stage,
• Toxicity,
• Bioaccumulation,
• Habitat modifying ability,
• Environmental impact (e.g. BPL index)
• Risk assessments (e.g. AS-ISK)
Platform for the collection, labeling, and storing of data on NIS discovered in recipient regions.
Data on NIS found in ports
Linked with the HELCOM/OPSAR JHP tool (ballast water management exemptions)

Fig. 1 AquaNIS (http://aquanis.ku.lt) is an example of a centralised information system that integrates data from the port baseline surveys and a wide range of other NIS monitoring programmes and research projects. Abbreviations: *BPL* biopollution index—that assesses the magnitude of the impact of invasive alien species on native species communities, habitats and ecosystem functioning (Olenin et al. 2007); *AS-ISK* aquatic species invasiveness screening kit—a decision-support tool for identifying potentially invasive aquatic taxa (Copp et al. 2016); *JHP* joint harmonised procedure for granting BWM exemptions (https://maps.helcom.fi/website/ra_tool, last accessed March 2024)

AquaNIS provides a platform to store data from PBS conducted in ports, which includes the Latin names of NIS found and basic information on environmental conditions in a port (salinity and temperature range, main habitats, etc.). Data on PBS which are submitted by local authorities to HELCOM/OSPAR database (Fig. 1) are automatically shared with AquaNIS and vice versa. Through the species name (and identification code), these data are linked to relevant information on the biological characteristics and impacts of the species. In addition, all species names are

associated with worldwide introduction event records, which help to determine the invasion potential of a NIS. Thus, the data from one biological survey in the port can be evaluated in the context of the constantly accumulating information from other ports and other regions of the world, which allows making more informed decisions.

Another BWM-oriented database was developed during the IPA-funded project 'BWM system for Adriatic Sea protection' (BALMAS). All BALMAS sampling results stored in the database were arranged in a format which allows a flexible data search to meet the BWM information needs of stakeholders, authorities and agencies. The database was considered as an integral part of the EWS and the Risk Assessment (RA) process for BWM exemptions (Velkavrh et al. 2016). The BALMAS HAOP database was accessible at www.balmas.eu, however, at the time of writing this contribution it was not available anymore.

3 Decision-Making on BWM Exemptions

The evaluation of whether a BWM exemption can be granted, as specified in Regulation A-4 of the BWM Convention (IMO 2004), is carried out by a risk assessment, which should be based on reliable data, including biological surveys of the ports in question (David et al. 2013, 2015; David and Gollasch 2019; HELCOM/OSPAR 2020). Databases were used for this process and two examples are BALMAS (see above) and HELCOM[1] databases. The data stored in these databases are an essential component for decision-makers to evaluate whether or not an exemption can be granted.

As a first step the species to occur in the ports for which an exemption is considered need to be compared (Fig. 2). This includes presence/absence and also abundance

information, currently not well documented in many databases (Meyerson 2011). Abundance data are important because species can occur at low abundance levels in a receiving port without a fully self-sustaining population, but further releases from a donor port where the species is higher in abundance could theoretically result in a sustainable population at a receiving port. In consequence, it would be unacceptable to discharge unmanaged ballast water in cases a certain species occurs in much higher abundance in any of the ballast water donor ports compared to a recipient port. Further, the occurrence of human pathogens and indicator microbes need to be documented to enable a risk assessment so that these details would need to be extractable from such a database as well. In addition, information about the natural spread of species, such as larval or other spreading stage duration, needs to be evaluated when considering exemptions as well as the salinity tolerance of the different developmental stages of the species (David et al. 2015; David and Gollasch 2019). Other than biological data, the database facilitating exemptions decisions needs to provide information on the salinity of the ports considered and information whether or not an eradication effort is ongoing against certain species (David et al. 2015; David and Gollasch 2019).

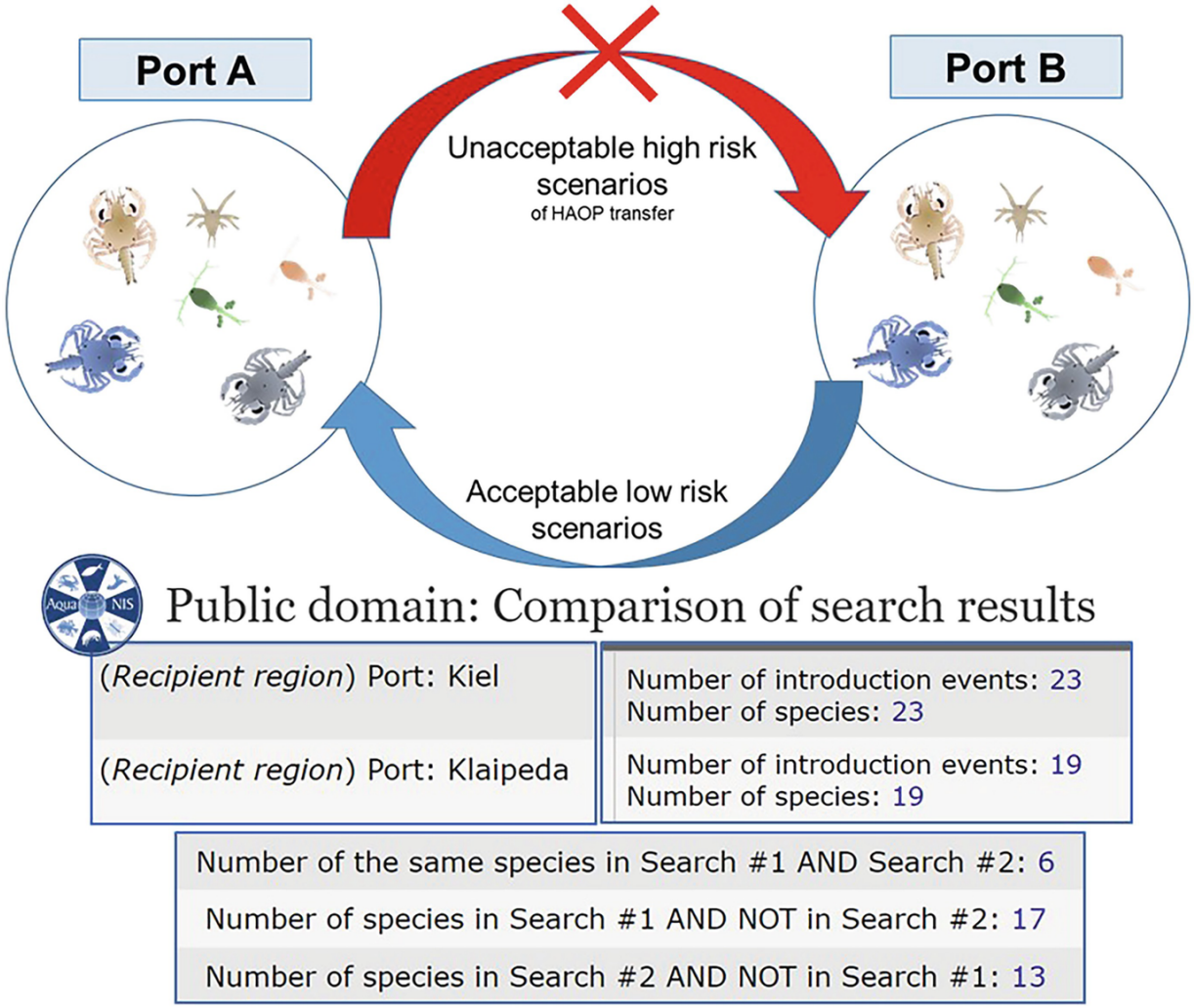
Port A
Port B
Unacceptable high risk scenarios
of HAOP transfer
Acceptable low risk scenarios
Public domain: Comparison of search results
(Recipient region) Port: Kiel
Number of introduction events: 23
Number of species: 23
(Recipient region) Port: Klaipeda
Number of introduction events: 19
Number of species: 19
Number of the same species in Search #1 AND Search #2: 6
Number of species in Search #1 AND NOT in Search #2: 17
Number of species in Search #2 AND NOT in Search #1: 13

Fig. 2 Top: Port-to-port risk analyses to decide whether an exemption from ballast water management can be granted. Bottom: Data analyses tool provided by AquaNIS that helps to compare the lists of species present in ports A and B. In this example: 24 species were recorded in the port of Kiel, 19 species in the port of Klaipeda; of these, 7 species are common to both ports, 17 species are found in Kiel and not found in Klaipeda, and 12 species are known from Klaipeda, which were not registered in Kiel. Further analysis is possible for NIS biological traits, their association with ballast water, known distribution range, etc. by clicking on the relevant numbers

4 Early Warning System

For an EWS, as stipulated in Regulation C-2 of the BWM Convention (IMO 2004) the timely provision of data from sampling surveys is key. It is clear that the earlier a new species is found, the more likely it is that its spread by

ballast water can be avoided and further that an eradication programme of a species may be successful.

New findings of species are usually published in scientific journals and this publishing process takes much too long to be suitable for EWS. As such an undesirable example, we can mention the database on NIS of the Black Sea, compiled as a result of the work of experts from six Black Sea countries in 2007–2013, including also earlier periods. According to the decision of the Advisory Group on Biodiversity Conservation of the Secretariat of the Black Sea Commission, this database was to become open for public use through AquaNIS only after the publication of a joint review of biological invasions in the Black Sea with the participation of six leaders of expert groups from all Black Sea countries as co-authors. Unfortunately, this data was never brought to a full-fledged peer-reviewed article and was published only as an electronic working document for CBD, containing many small errors (BSC 2017). However, the disclosure of such a dataset allows it to be transferred to centralised databases and widely used, subject to proper quality control to avoid transmission of errors.

In contrast, a positive example is that ICES has already recognised AquaNIS to store information about NIS generated by its Working Group on Introductions and Transfers of Marine Organisms and the Working Group on Ballast and Other Ship Vectors thereby avoiding to set up their own separate databases for these species findings. In addition to timely notification of new species records, by using AquaNIS, an enormous amount of efforts to summarise the situation of introduced species in ICES Member States is saved. In the past these species summaries were produced by the chairpersons of these working groups and enthusiastic group members and in the pre-digital times it took very long, up to several years, to bring the data together (Munro et al. 1999; Gollasch et al.

2007; Pederson et al. 2017). Using a database like AquaNIS, such overviews of introduced species and related introduction pathway and vector information may become available almost instantly by using the online search engine of AquaNIS thereby enabling prompt and concerted actions against certain species.

One of the few examples of a regional EWS is the tool developed for the Baltic Sea region during the COMPLETE project (www.balticcomplete.com), which aims to reduce the risk of spreading HAOP by minimising the uptake and discharge of ballast water which could be harmful to the recipient port or area. Technically, the EWS is embedded in AquaNIS as a special functional module (Fig. 3). On receiving data from local sources, the national data provider connects to the AquaNIS EWS module and fills out a special form, indicating the name of the species of concern, country and port from which the data are reported, species distribution, whether it is the cause of an outbreak, known species impacts and other relevant information. A drop-down menu is used as much as possible to facilitate the data entry process and to minimise human errors. As soon as the name of a species is entered, the data provider receives a fact sheet, automatically generated by AquaNIS which contains relevant data on the species in question, e.g., its impacts and distribution (Srebalienė et al. in prep.). Then, an alert and the supporting fact sheet are sent to the EWS Expert Group consisting of international specialists in the management of HAOP and ballast water, which decides on the need to propagate a warning signal. Finally, the warning signal is sent to all registered recipients designated by the participating parties as national focal points (e.g., Maritime authorities, Ministries of Transport and/or Environment), which are to decide which recommended action to take at the national level.

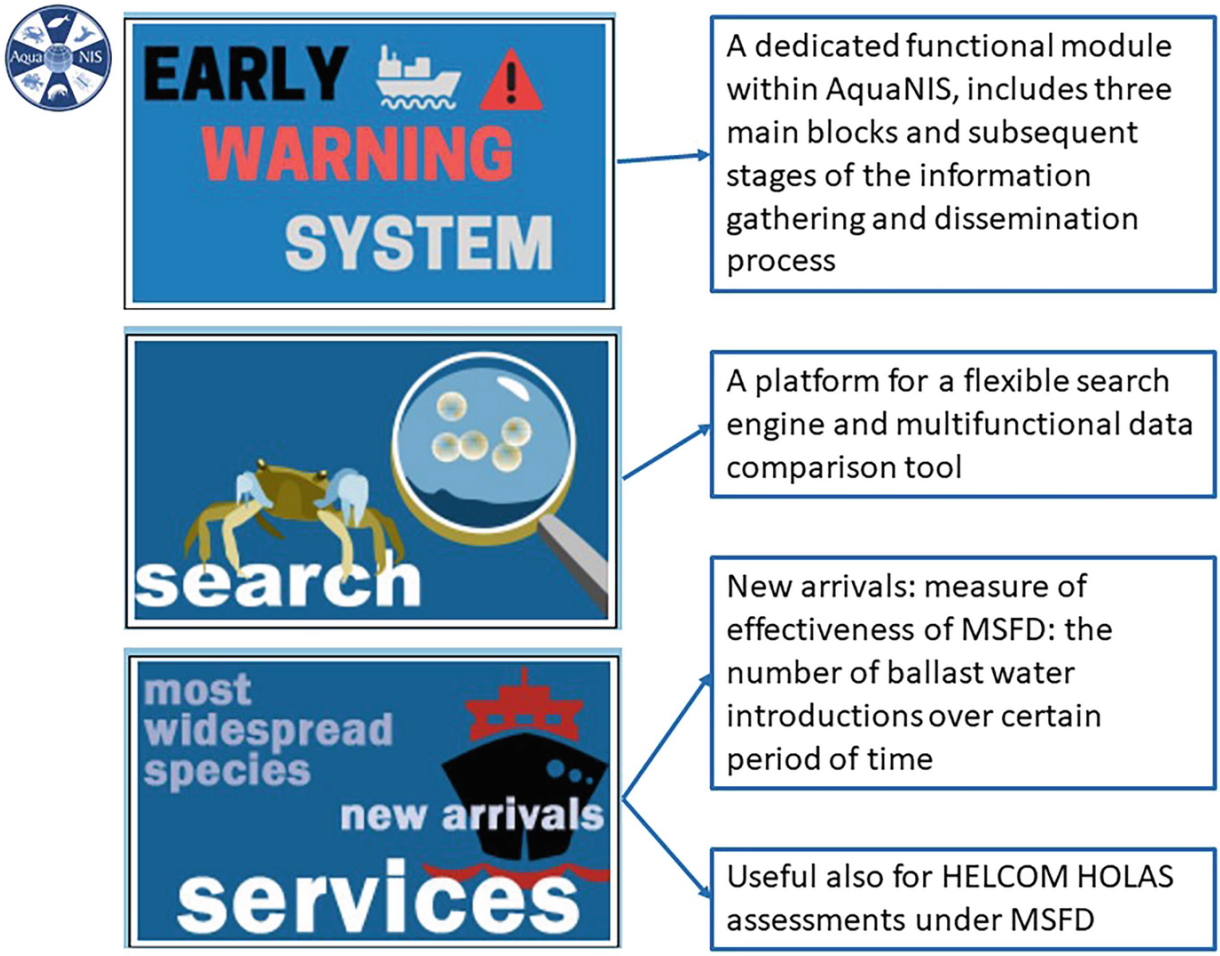
EARLY
WARNING
SYSTEM
A dedicated functional module within AquaNIS, includes three main blocks and subsequent stages of the information gathering and dissemination process
search
A platform for a flexible search engine and multifunctional data comparison tool
most widespread species
new arrivals
services
New arrivals: measure of effectiveness of MSFD: the number of ballast water introductions over certain period of time
Useful also for HELCOM HOLAS assessments under MSFD

Fig. 3 An Early Warning System (EWS) for the detection of Harmful Aquatic Organisms and Pathogens (HAOP) built into AquaNIS. It provides a platform for: (1) reporting HAOP detection data in or near the port, (2) deciding whether an international expert council should send a warning signal, and (3) sending a warning to registered users such as port authorities and environmental agencies. AquaNIS EWS makes the most of other stored data, such as molecular information, availability of metadata. Abbreviations: *HOLAS* holistic assessment of the state of the Baltic Sea environment; *MSFD* Marine Strategy Framework Directive (EU 2008)

5 Species Control and Eradication Programmes

Early information about new species findings are essential because it is more likely to successfully run an eradication effort before the new species becomes widely established and starts spreading (Magaletti et al. 2018). However, in

marine waters limited success is documented in eradication plans (e.g., Anderson 2005), but it is increasingly noted that control or management efforts are beneficial strategies (McKenzie et al. 2017).

Control programmes for certain species, known to be negatively impacting elsewhere, may be established to enable a timely eradication or management effort once the species was found. As an example, German scientists frequently check in AquaNIS for newly found species in neighbouring countries along the North and Baltic seas, especially the Netherlands, Denmark and Poland as direct neighbours, to alert the scientists involved in coastal sampling studies which are targeted to record formerly introduced species and new species findings. An interesting case is *Didemnum vexillum* which, until 2015, was unknown to occur in German waters, but it was found in several European countries (Kleeman 2009; Laing et al. 2010; Nimmo et al. 2011; Graham et al. 2015; McKenzie et al. 2017), including the direct German neighbour, the Netherlands, where it was first found in 2009 (ICES 2011; Buschbaum et al. 2012). The species spread eastwards and was therefore expected to reach Germany. Eventually in 2016 it was first recorded in Hörnum harbour, Sylt Island (Gollasch and Nehring 2017; Neobiota-Plattform 2021). The German monitoring team expected this finding due to the known occurrence of the species in German neighbouring and nearby countries as documented in the AquaNIS database. Therefore, a frequently updated and checked database would be beneficial when planning control or eradication programmes of certain species. The additional alert time after a species was found in neighbouring countries until it reached Germany could theoretically be used to (a) form a concerted action on a regional basis to avoid or slow down its spread, and (b) check if eradication is possible and what measures may be

used. Unfortunately, this was not the case for *Didemnum vexillum* as it is known that eradication efforts, such as physically removing the species, are counter-productive and may even facilitate its spread. This is because the establishment of colonies may develop from very small fragments (Kleeman 2009; Nimmo et al. 2011; Morris and Carman 2012; McKenzie et al. 2017). *Didemnum vexillum* eradication events were performed in several countries applying various methods, e.g., in New Zealand and United Kingdom, but with no or limited long-term success (Coutts and Forrest 2007; Holt and Cordingley 2011; Nimmo et al. 2011; McKenzie et al. 2017).

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6 Measuring the Effectiveness of the BWM Convention

Strict BWM rules, applied in recent decades in US and Canada, resulted in no introductions of new fresh water species in the Laurentian Great Lakes Region between 2006 (Scriven et al. 2015) and 2016 when the new Copepod *Mesocyclops pehpeiensis* was found in Lake Erie. This species is unlikely a ballast water-mediated introduction, it was found in US waters earlier and has a history of being transported with ornamental and aquaculture activities (Sturtevant et al. 2019). As ballast water transport cannot be ruled out completely, this species is mentioned here as possible ballast water introduction. The effectiveness check was probably to a large extent supported by the Canadian National Aquatic Invasive Species Database (DFO 2015). A similar approach to check whether or not the BWM Convention is effective may be taken, especially after Regulation D-2 applies to all ships, which is in September 2024.

In fact, the effectiveness of the BWM Convention as well as several other legal and administrative instruments

aimed to reduce the spread of HAOP can only be measured by success in the prevention of new introductions, which have to be based upon reliable data generated by appropriate surveys and monitoring programmes (see above). For this purpose, an indicator ‘New arrivals’ was proposed, which indicates the number of new NIS (i.e., potential HAOP) in an assessment unit, recorded within a certain period (Olenin et al. 2016b). The indicator helps to assess the rate of introductions at different geographic scales, from the coast of a country to the entire regional sea, or even on a wider geographic scale that includes two or more adjacent seas. Data on new arrivals can be further analysed in terms of introduction vectors (e.g., how many species were introduced by ballast water and how many by other vectors such as aquaculture?) or help to distinguish between primary introductions entering the regional sea and its secondary spread (Olenin et al. 2016b). It is important that the technical precondition for the calculation of the ‘New arrivals’ indicator is the availability of a global, continuously updated and verified source of information on aquatic invasive species, including HAOP (Figs. 3 and 4).

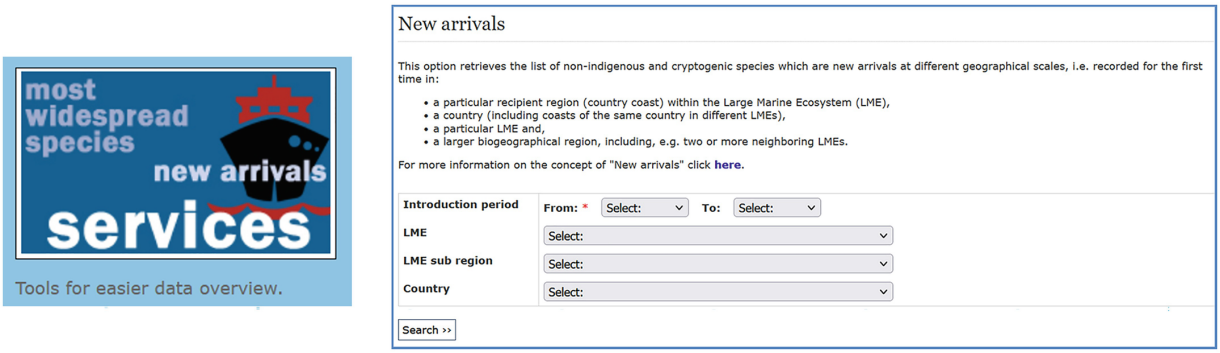
most
widespread
species
new arrivals
services
Tools for easier data overview.
New arrivals
This option retrieves the list of non-indigenous and cryptogenic species which are new arrivals at different geographical scales, i.e. recorded for the first time in:
• a particular recipient region (country coast) within the Large Marine Ecosystem (LME),
• a country (including coasts of the same country in different LMEs),
• a particular LME and,
• a larger biogeographical region, including, e.g. two or more neighboring LMEs.
For more information on the concept of "New arrivals" click here.
Introduction period
From: *
Select:
To:
Select:
LME
Select:
LME sub region
Select:
Country
Select:
Search ››

Fig. 4 AquaNIS is equipped with a built-in tool to retrieve data on new arrivals. The hierarchical principle of geographic information arrangement applied in the system allows retrieving data for individual countries, separate large marine ecosystems and larger biogeographical regions. Since all introduction event records include the dates of species arrivals into particular recipient regions, it is possible to distinguish primary introductions and

secondary spread of species with sufficient accuracy (for details see: Olenin et al. 2016b)

7 Discussion

The number and availability of global, regional and national web resources on HAOP rises, however key information needs for bioinvasions management, including BWM, are only partially available. The key problem is that it is easier to obtain funding for developing new databases than for database collaboration, adaptation, improvement and maintenance (Simpson et al. 2006). However, there are many advantages of a centralised and open-access database like AquaNIS as described above. The utility of a database depends not only on the technologies used and the deliverables obtained by the project, but whether information provided in the database is demanded by users over time, and how the system is maintained after the expiration of the project (Olenin et al. 2014). The advantage of a live database, which is constantly updated and verified by experts, is that it is constantly growing as species introduction data and other related information accumulates in the existing infrastructure. Another advantage is that there is no need to re-enter multiple data, as in a centralised database, one record can be used for different applications, following the principle of 'collect once, use many times' (Whomersley et al. 2015), which is especially important in times of financial hardship and limited availability of resources to collect, validate and enter data into the system. Consequently, data gathered should be easily available to the shipping industry and authorities being responsible for the BWM Convention implementation.

Long-term funding needs to be secured to ensure that continuous updates and data quality control does not depend solely on the enthusiasm of database developers

and data providers. It is therefore proposed that a self-funding system may be established with financial support from national or regional bodies. To establish this, an evaluation of who predominantly benefits from the data may be carried out and the prime users may be approached asking for financial support for data use and storage. Regarding regional support, as an example, authorities like ICES, HELCOM or OSPAR may be approached. As the budget of such authorities is usually tight, one joint HAOP (and NIS) database would be of clear benefit. The key advantages of the existence of a single long-term database need to be clearly described, which include (a) that the data are entered once only so that not all authorities need to finance data entries in their individual databases, (b) initial checks in BWM related applications, such as to compare species lists of ports when considering exemptions from BWM requirements and (c) the automatic alert function for new species records as this would be of benefit to several users.

To support correct BWM decisions the process to collect reliable data is critical as this is the basic information on which decisions are based so that the consequence of faulty data input results in a wrong answer. Two main aspects need to be considered in this regard: the availability and reliability of data (David and Gollasch 2015). Data availability means that correct data need to be available at the right time. As a result, all data needed for the entire process to enable making all decisions are essential. It is also very important that these data are available timely to prevent vessels from uptaking water containing critical HAOP.

The data reliability refers to quality and quantity aspects. The quality of the data is of paramount importance and means that all DSS input data should originate from reliable sources. Regarding data quantity, there should be sufficient comprehensive data to be statistically robust.

Most of the data received from external sources as well those from the decision process have firstly to be managed properly, secondly be safely stored and accessible and thirdly may be best arranged in a DSS database. This database will provide DSS with the needed information, as well as that it is serving the needs of outer sources, including to share information with other stakeholders, to review the entire DSS process and also as a back-up for a subsequent review process of a single decision.

It is not only the data availability and its quality what concerns, it is also the time aspect. Time should be allocated not only for processing the samples from monitoring activities in ports and adjacent areas promptly, but also for the entry into the database. Earlier studies recommended a time period of no more than 4–5 days when planning to support an EWS to enable a timely warning; this means that the data collected should be stored in a routinely updated database (Magaletti et al. 2018). To give researchers the expected credit of new species records, the databases can be restructured so that, after a new record, the authorship of the data is clearly identified in a statement that can be used as a simplified reference.

For a database to be fit for purpose, it is necessary to assess in detail the needs of potential users. One example is the often overlooked meaning of HAOP. Databases for BWM use should take into account that the IMO BWM Convention is about HAOP and not just NIS or even IAS. That being said, the ideal database for meeting the needs of BWM should have a section on harmful native species, which is largely absent as most databases were designed to document NIS or IAS and ignored possible wider use.

Regional approaches are preferred over national databases on the same subject as data extraction becomes cumbersome in cases when multiple databases need to be consulted. However, different users may benefit from different databases. As an example, the BWM compliance

history data of vessels may be stored in a different database than the above-mentioned biological information for BWM exemptions, EWS, control and eradication programmes, which may all be stored in one database. This is suggested because compliance history is a completely different subject and has no linkage to detailed species information. The European Maritime Safety Agency (EMSA) has its own electronic online system and database to support EU Member States and the Commission mainly for targeting of vessels for PSC, compliance history of vessels, and PSC performance statistics.[2]

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8 Conclusion

Ballast water management requires a significant amount of constantly updated and reliable data. Decisions to grant BWM exemptions, to provide early warning of the detection of harmful organisms, to inform seafarers where ballasting should not be carried out, to assess the effectiveness of measures to prevent new introductions, etc. should be based on scientific knowledge. And this knowledge should be communicated to managers on time and in an understandable manner.

The only way to promptly provide such data is to create, maintain and constantly update centralised databases such as AquaNIS. Such an information system should be multifunctional, based on the principle of ‘collect data once, use it many times’, so that the accumulation of data allows not only their operational use to meet urgent needs for decision-making, but also for analysis and forecasting. For the purposes of the BWM convention, it is also important that such a database contains information not only on introduced alien species, but also on local harmful organisms and pathogens which can be transferred with ballast water.

Finally, the information system must have institutional support at the level of regional or, better, global organizations and conventions, so as not to depend solely on the enthusiasm of its developers and data providers.

Acknowledgements

This work was supported by the INTERREG Baltic Sea Region project COMPLETE (Completing management options in the Baltic Sea Region to reduce risk of invasive species introduction by shipping, #R069)—for S.O., S.G., M.D. and A.N.; by the Lithuanian-Ukrainian bilateral cooperation in the field of science and technology project MARSTAT (Measuring the marine ecosystem health: concepts, indicators, assessments, # S-LU-20-1)—for M.S. and S.O., and by the European Social Fund under the 'Development of Competences of Scientists, other Researchers and Students through Practical Research Activities' measure DORAS (Development of a system for detection and risk assessment of harmful aquatic organisms and pathogens # 09.3.3-LMT-K-712-19-0083)—for G.S.

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M. David, S. Gollasch (eds.), *Global Maritime Transport and Ballast Water Management*, Invading Nature - Springer Series in Invasion Ecology 16
https://doi.org/10.1007/978-3-031-48193-2_10

Five Years of "Lively" Implementation of the Ballast Water Management Convention: Global Guidance, Regional Challenges and National Issues

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Abstract
This chapter describes the main legal and implementation challenges emerged after the entry into force of the International Convention for the Control and Management of Ships' Ballast Water and Sediments, 2004 (BWM Convention) on 8 September 2017. Main obligations are reviewed, focusing on the more complex features, reporting relevant arrangements and guidance provided by

the International Maritime Organization (IMO) non-binding documents. Key issues to be addressed by States after ratification are identified, when available, including examples of the actions taken at regional and national levels. Inconsistencies of the global rules and aspects not legally covered are highlighted as emerged in practice. Examples of different actions taken by States and the role played by regional organizations are also reported.

Keywords Ballast Water Management Convention – Implementation – Legal issues – National and regional challenges – Non-indigenous species – Harmful Aquatic Organisms and Pathogens

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1 An Environmental Issue, a Shipping Response

The first substantial problems connected to the introduction of organisms into natural environments outside their native range, both terrestrial and marine, were recorded at the beginning of last century (Elton 1958; Hallegraeff and Bolch 1992). Since then, the spreading of non-indigenous species (NIS) and other organisms, such as bacteria, has resulted in damages across different regions of the globe (Katsanevakis et al. 2014).[1] Several human activities are actual pathways for these introductions, whether intentional or not (i.e., agriculture, trade, transport, shipping, aquaculture, and tourism) (Minchin et al. 2005; David and Gollasch 2015). Once introduced into new environments, the eradication of NIS is mostly impossible (Genovesi 2005; Hayes et al. 2005). Climate change further exacerbates the inherent dangers of introductions (Pederson et al. 2011).

As the consciousness of these negative consequences emerged, along the years several international legal

instruments recognized the problem, originally mainly within the corpus of international environmental law (*inter alia*, Hewitt et al. 2009). Multilateral treaties and declarations affirmed the States duties to protect the natural environments and biodiversity from the introduction of NIS, irrespectively of relevant sources, calling for the adoption of national measures and promoting cooperation at regional and global levels (Gollasch et al. 2015b). These international instruments variously referred to the need to "prevent," "reduce," "control," "manage" or "eradicate" the "introductions" or the "spreading" of "exotic" or "alien," "non-indigenous," "non-native," "harmful," "environmentally dangerous," "species," "pathogens" and/or "organisms." Each environmental instrument used a different terminology with the consequence that relevant legal application scopes vary.

In regard to the marine environment, the 1982 United Nations Convention on the Law of the Sea recognized the issue (LOS Convention 1982). A detailed review of the ballast water regime in light to the LOS Convention is not dealt with in this chapter. However, it is worth noting that the inclusion in the "pollution" definition of the introduction of NIS requires an interpretative exercise, which might also shape the relations of other LOS Convention principles (e.g., on enforcement or monitoring) with the ballast water management regime. Furthermore, among LOS Convention general provisions on the protection and preservation of the marine environment is the duty of States to "take all measures to prevent, reduce and control (...) the intentional or accidental introduction of species, alien or new, to a particular part of the marine environment which may cause significant and harmful changes thereto" (LOS Convention 1982, Part XII, Art. 196). This provision envisages the need for national

measures to address any introduction of “alien” or “new” species, regardless of its source, producing, in a cause-effect relation, “harmful changes” of a certain severity in the marine environment. Finally, it can be mentioned that the States general obligation of formulating and elaborating on a global or regional basis as appropriate “international rules, standards and recommended practices consistent with this Convention, for the protection and preservation of the marine environment” should be considered as covering also the environmental problems linked to NIS introductions (LOS Convention 1982, Part XII, Art. 197).

The global action to address the risks represented by NIS made a significant step further with the 1992 UN Conference on Environment and Development (UNCED) held in Rio de Janeiro (Brazil), a milestone in the development of international environmental law (UNCED 1992). The Rio final declaration affirms fundamental principles of environmental law such as the prevention and precautionary approaches, also stressing the States responsibility to conserve their biodiversity and to ensure that activities within their jurisdiction or control do not cause damage to the biological diversity of other States or of areas beyond the limits of national jurisdictions. In this context, the global mandatory framework on biodiversity developed within UNCED, the 1992 Convention on Biological Diversity (CBD 1992) declined in Art. 8 (h) the duty of States “as far as possible and as appropriate” to “prevent the introduction of, control or eradicate those alien species which threaten ecosystems, habitats or species” as a part of the *in-situ* measures needed for the conservation of biodiversity. Furthermore, the Agenda 21 plan of action, a comprehensive set of non-binding global commitments resulting from UNCED, focused on shipping as a vector of NIS introduction. In such plan, with a view to

protect biodiversity, States were called to assess the need to consider—either individually, bilaterally or through relevant international organizations—additional measures on shipping, including “the adoption of appropriate rules on ballast water discharge to prevent the spread of non-indigenous organisms” (UNCED 1992, para. 17.30).

In 2002, States Parties to the CBD formulated a specific framework on NIS approving “Guiding principles for the implementation of article 8(h)” as well as “Guiding principles for the prevention, introduction and mitigation of impacts of alien species that threaten ecosystems, habitats or species” (CBD 2002). With the Strategic Plan for Biodiversity 2011–2020, “invasive alien species” were considered as direct drivers of biodiversity loss, also becoming the focus of one of the Aichi Biodiversity Targets to be reached by 2020 (CBD 2010, Aichi target 9). Hence, the Aichi target identified as threatening species those “invasive” aside from “alien.” Recent CBD evolutions tackle further economic sectors (i.e., the growth in e-commerce of alien species and the trade in live organisms) in which to encourage the mobilization of data and the development of classifications and research in the field (CBD 2018).

Outside the biodiversity/environmental law framework, States developed within different international organizations other legal instruments and commitments addressing NIS introductions in the sectors of agriculture, breeding and health (i.e., the Office International des Epizooties, the regional plant protection organizations, the Food and Agriculture Organization and the World Health Organization).

In line with these global commitments, States have adopted, individually and through regional cooperation, environmental measures and monitoring programmes to address the presence and impacts of NIS, both terrestrial and aquatic. This is the case of the European Union, whose member States shall comply with a legislation on “invasive

alien species," also covering the aquatic environment (EU 2014). Furthermore, the EU Marine Strategy Framework Directive, included measures addressing alien species to be extended through regional cooperation with non-EU member States across European marine regions and sub-regions (e.g., Mediterranean Sea, Baltic Sea, North-West Atlantic, Adriatic Sea) (EU 2008). The EU legal framework also has in place legal requirements on the monitoring of the pathogens presence, as a part of legislation to protect human health (EU 2006). These different legal initiatives coexist with those addressing the shipping vector of introduction. Soon their convergence may smooth efforts of both authorities and the shipping community for the implementation of global shipping standards in European regional seas (Rak et al. 2019).

In parallel with the evolution of main scientific findings and of environmental law global commitments, the maritime community addressed the contribution of the shipping activities to the introduction and spreading of Harmful Aquatic Organisms and Pathogens (HAOP) into new environments. HAOP include all potentially harmful alien or NIS, as well as cryptogenic and impacting native aquatic species and pathogens (David et al. 2013a; Gollasch et al. 2015a), which can threaten human health, environment, property and resources. Several maritime practices are relevant in this regard (i.e., biofouling and aquaculture) as they increase the presence of HAOP in aquatic environments. However, the States cooperation in addressing ballast water vector of introduction was at the forefront, and it tackled the routine operation of most ships worldwide, essential during loading and unloading of cargoes.

The International Maritime Organization (IMO), the agency of the UN system specialized on shipping matters, considered the need of specific studies on species transport with ballast water already in 1973 (IMO 1973). After the

UNCED call, the Organization took up the challenge to prepare an instrument addressing the issue. Based on the work initiated in 1991 within its Marine Environment Protection Committee (MEPC), the international discussion led in a relatively short time to the adoption of a first international resolution on the matter (IMO 1993) addressing the prevention of organisms transport in ballast water. Along with the consciousness of the difficulties in the prevention of species' movements in ballast water, the IMO work continued and in 1997 the Guidelines for the Control and Management of Ships' Ballast Water to Minimize the Transfer of Harmful Aquatic Organisms and Pathogens were adopted by Resolution A.868(20) (IMO 1997), replacing the 1993 Resolution (Gollasch et al. 2015b).

The work aiming at developing a mandatory legal instrument continued and, in 2004 IMO reached consensus on the final text of the Ballast Water Management (BWM) Convention. The 2004 International Convention for the Control and Management of Ships' Ballast Water and Sediments (hereinafter, BWM Convention) addresses the role of the shipping sector in the worldwide spread of HAOP. The integration of biodiversity concerns into a shipping treaty led to the elaboration of specific terminology. The BWM Convention refers to HAOP defined as "harmful aquatic organisms or pathogens which, if introduced into the sea including estuaries, or into fresh water courses, may create hazards to the environment, human health, property or resources, impair biological diversity or interfere with other legitimate uses of such areas" (IMO 2004b, Art. 1.8). Differently from environmental law treaties which mention invasive, non-indigenous or alien species, the BWM Convention considers HAOP, which also refer to native species when they cause the described impacts, including health or economic hazards. As reflected in the title of the BWM Convention

(IMO 2004b), due to the inextricable physical mixture of ballast water with sediments, which later may settle out in ships' ballast tanks and may accumulate inside the tanks, the BWM Convention covers also HAOP contained in sediments.

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2 The Challenging Nature of the BWM Legal Regime

More than 90% of the world's commercial trade uses the maritime transport modality (OECD 2023), this high percentage being poorly affected even by the global COVID-19 pandemic (Millefiori et al. 2021). The huge global shipping activity, with maritime everyday transport of freights and commodities, can count on the freedom of navigation guaranteed by the law of the sea as well as on global standards, able to improve worldwide uniformity of navigation requirements, reducing States' unilateral actions and differences between jurisdictions. Within IMO, many shipping conventions are negotiated addressing different aspects of the prevention and control of marine pollution from ships; since 1984 a further objective of the organization introduced in the relevant treaty in 1977 (IMO 1948).

As a treaty with global application, the BWM Convention provides therefore a uniform regime on a routine ships' operation, aimed at preventing risks to human health, marine biodiversity, as well as to property and resources, posed by HAOP introductions. Indeed, despite the new regime, some States still maintain different national standards for ships calling at their ports, e.g., the United States where, however, the difference in standards are progressively aligning (Molina and Drake 2016). However, compared to other IMO conventions addressing the prevention and control of marine pollution from ships, the

BWM Convention presents several specifics influencing its implementation, some of which led some authors to label the instrument as an “unconventional” convention (Pughiuc 2012).

The BWM Convention stipulates types of obligations that are similar to those of other shipping treaties. In short, two ballast water management requirements related to discharges are identified, e.g., the Ballast Water Exchange Standard (D-1 standard) and the Ballast Water Performance Standard (D-2 standard). While the D-1 standard involves the ship’s operations, the D-2 standard regards the quality of discharges. The D-2 standard shall be satisfied according to a specified phase-in calendar and ships to be compliant may be equipped with type approved ballast water treatment technologies. The BWM Convention also stipulates mandatory ship-specific onboard documentation (e.g., the Ballast Water Management Plan and the Ballast Water Record Book) and establishes an international survey and certification regime. The Port State Control activities are also addressed.

Since the moment of the BWM Convention adoption, challenges linked to availability of technologies and to its adequacy to comply with the new global requirements emerged. Although the high presence of technical contents is a characteristic of many IMO treaties, in the case of the BWM Convention the number of guidelines and guidance documents to be issued was unusually high, indicating the existence of technical aspects not properly solved. The 2004 final diplomatic conference invited IMO to develop, as a matter of urgency, guidelines and procedures on many different aspects in order to ensure a global and uniform application of the relevant requirements (IMO 2004a; Pughiuc 2012). Both the development of robust decision-making tools and of a substantial technical cooperation programme were stressed (IMO 2004a). Significant uncertainties arose within the shipping community in

connection with operational issues, reinforcing the reluctance of industries to bear the costs of the retrofitting of existing ships with Ballast Water Management Systems. The efficacy of the treatment systems available on the global market was questioned and in 2007, soon after the closure of the diplomatic conference, IMO recognized the issue, underlining the problems of ships to which the standards would have to apply first. The need to provide certainty and confidence in the application of the BWM Convention, thereby assisting shipping companies, shipowners, managers and operators was emphasized, together with the need to support the timely planning of shipbuilding and equipment manufacturing industries (IMO 2007c). The issues related to the unavailability of proper technologies were not common to other IMO conventions, which normally set, since the beginning, detailed technical aspects of ships' requirements, i.e., vessel construction schemes, operational requirements, and lists of substances.

Together with the uncommon guidance needed and the technological issues, other features are specific to the new regime. The entry into force conditions of the BWM Convention were set 12 months after the date on which not less than 30 States, with the combined merchant fleets of which constitute not less than 35% of the gross tonnage of the world's merchant shipping have ratified or signed it without reservations regarding further national procedures (IMO 2004b, Art. 18). These conditions have been met on 8 September 2016, and the BWM Convention entered into force on 8 September 2017. The combination of the two criteria—number of States and percentage of the world's fleet—is common in almost all IMO conventions as it helps ensuring the level of respect of shipping standards worldwide. However, compared to one of the key treaties on shipping sources of pollution, e.g., the International Convention for the Prevention of Pollution from Ships (MARPOL 73/78 Convention), in the BWM Convention the

number of agreeing States is twice as high (30 instead of 15) and the tonnage percentage requirement is lower (35 instead of 50). Some authors noted the reduction of the dominance of open-registry States implied by this choice, significantly rebalancing States' power at IMO, implied by these differences in entry into force requirements (Firestone and Corbett 2005). Furthermore, the long timeframe (more than 13 years) needed for the BWM Convention entry into force, which nearly doubled the average time needed by the other IMO treaties on ships' pollution prevention, is a further evidence of peculiar difficulties.

Other legal specifics influencing implementation are explored in detail below, however, it is worth noting how the regime outlined by the BWM Convention legally establishes a peculiar connection of the actual operation of ships with the characteristics of the marine environment in which navigation takes place. In other words, while typically in IMO conventions the legal provisions focus on the shipping activity, in BWM regime the qualities of the surrounding environment may influence the implementation and actual compliance with standards. In certain cases, an in-depth knowledge of the environmental, natural and quality features of the sea is needed. This is evident in the very complex exceptions' regime foreseen in the BWM Convention, implying bilateral and multilateral cooperation, and requiring the availability of monitoring data, as well as in the provisions on warnings (see in detail below). The need for States to have a certain knowledge of the marine environment is also implied by those provisions asking to encourage ships to avoid, as far as practicable, the uptake of ballast water and sediments potentially containing HAOP (IMO 2004b, Art. 2.8).

To address the challenges inherent in this new legal instrument, some months before its entry into force, the IMO MEPC agreed on an Experience Building Phase,

during which ships should not be penalized (sanctioned, warned, detained or excluded) solely due to an exceedance of the ballast water performance standard provided certain conditions are satisfied (IMO 2017d). The basic assumptions were the recognition that non-compliance with the D-2 standard may depend on reasons beyond the control of the shipowner and ship's crew, and that challenges arose during the BWM Convention implementation that were not foreseen at the time of its adoption. Through the Experience Building Phase the early concerns raised by many States and the shipping community were taken into account by envisaging, during a certain period, the gathering and analysis of data on implementation, providing a systematic and evidence-based process for reviewing and improving implementation. In 2022 the main findings of the Experience Building Phase were presented, including associated data. The data analysis is still ongoing, and the development of a Convention Review Plan and a list of prioritized subjects were agreed upon. A time plan of the assumed workload is expected to end in 2026 (IMO 2022c).

The problems faced during the BWM Convention implementation resulted in a number of amendments to the BWM Convention regarding: the schedule and conditions of the standards phase-in (IMO 2018c, Reg. B-3), the introduction of the Code for Approval of Ballast Water Management Systems (BWMS Code) which turned G8 Guidelines into mandatory provisions (IMO 2018a, Reg. A-1 and D-3, and IMO 2018d) and the surveys regime (IMO 2018b, Reg. E-1 and E-5). In 2020 a consolidated text of the BWM Convention has been compiled by IMO, to which this chapter refers (IMO 2004b).

3 Review of Main Implementation Issues

3.1 Basic Application

(a) *The application scope (with regard to ships)*

The BWM Convention is applicable to all ships, regardless of their size, designed or constructed to carry ballast water, entitled to fly the flag of a contracting Party. It is also applicable to ships not entitled to fly the flag of a Party, but which operate under the authority of a Party (IMO 2004b, Art. 3.1 and 3.2. a). “Ships” are vessels of any type whatsoever operating in the aquatic environment. This definition in Art. 1.12 includes floating platforms without own propulsion, floating crafts and floating storage units (FSUs). Even if the BWM Convention does not apply to permanent ballast water in sealed tanks that is not subject to discharge, still it applies to the relevant ship.

The broad definition of ship provided is consistent with the environmental purpose of the BWM Convention: the possibility of HAOP transfer is inherent with the management of ballast water and all ships operating with ballast water may act as vectors. However, the surveys regime only applies to ships of 400 gross tonnage and above and floating platforms, FSUs and floating production storage and offloading vessels (FPSOs) are excluded from the surveys. The inclusion of this type of structures under the notion of ships is currently being studied because of its consequences on maritime liability and insurance matters (Musi 2017).

As other IMO treaties, the BWM Convention does not apply to any warship, naval auxiliary or other ships owned or operated by a State and used, for the time being, only on Government non-commercial service (Art. 3.1 (e)). Each

Party shall anyway ensure, by the adoption of appropriate measures not impairing operations or operational capabilities, that such ships act in a consistent manner, so far as is reasonable and practicable, with the Convention. Unfortunately, no reviews on how Parties implemented this obligation are available yet.

Further, questions regarding the application of the BWM Convention on specific types of ships and tanks arose. This is the case of the applicability to hopper dredgers, when taking up water during dredging operations. Hopper dredgers can be equipped with large suction pipes, ballast tanks and multiple high-capacity pumps. The “hoppers” are the cargo compartments where the dredged material is contained and transported. Due to the technical features of dredging, a question emerged whether the water in the hopper area matches the definition of “ballast water” as water taken on board to control trim, list, draught, stability or stresses of the ship (IMO 2004b, Art. 1.2). A specific IMO Circular (IMO 2011b, BWM.2/Circ.32) clarified this aspect, concluding that water in the compartments of the hopper area is considered outboard water and not water taken aboard and used to control trim, list, draught or stresses. However, the evaluation on applicability should be made on a case-by-case basis, e.g., as long as the water in the hopper of a dredger is not used for stability purposes the BWM Convention would not apply, while water in separate ballast tanks used for stability purposes would fall under its scope.

Based on the definition of ballast water, the same logic would apply to fishing vessels with Refrigerated Sea Water (RSW) systems, which are used on board to handle, store and preserve large catches by recirculating sea water through appropriate tanks and the chilling system. The reasoning can be extended to water from forepeak tanks feeding the Refrigerated Sea Water tanks as in this case it would not be used to control trim, list, draught, stability or

stresses of the ship. However, heeling tanks/anti-rolling tanks when containing ballast water not permanently sealed should in any case fall within the scope of the BWM Convention. Some States also questioned the possible application of the BWM Convention to seagoing fishing vessels using brine as a refrigerant, and IMO MEPC agreed that this brine water mixture is not considered as ballast (IMO 2018g, point 15.8).

The applicability of the BWM Convention to mobile offshore units was the focus of a specific circular which provided clarifications concerning mobile offshore units, e.g., on self-elevating units (SEU) and column stabilized units (CSU) and the application of the discharge standard requirement in the “same location” and while transiting to other areas as well as clarification on the survey regime (IMO 2013, BWM.2/Circ.46).

(b) *The application scope (with regard to spaces and voyages)*

The BWM Convention only applies to international voyages, meaning those voyages that connect two different national jurisdictions. Although this limitation is not explicitly stated in the text, it is the consequence of the provision on application, where it stipulates that the BWM Convention does not apply to ships of a Party, which only operate in waters under the jurisdiction of that Party (IMO 2004b, Art. 3.2). However, even in the cases described above, Parties are not left totally free, as each of them bears the legal responsibility to determine whether the discharge of ballast water would impair or damage the environment, human health, property or resources under its jurisdiction, or those of adjacent or other States, and to adopt consequent measures.

Furthermore, according to the same provision, the BWM Convention does not apply to ships of a Party which only

operate in waters under the jurisdiction of another Party, subject to the authorization of the latter Party for such exclusion (Art. 3.1 (c)). In these cases, the Parties granting such authorizations bear the explicit responsibility that operations would not impair or damage their environment, human health, property or resources, or those of adjacent or other States. Any Party not granting such authorization is obliged to notify the Administration of the ship concerned. Other characteristics of these authorizations, i.e., its implicit or explicit character and procedural steps are not specified and the Party might establish national indications.

A third case in which the BWM Convention does not apply is when ships only operate between waters under the jurisdiction of one Party and on the high seas. In this case, the coastal State/flag State may determine that the BWM Convention applies when the discharge of ballast water from such ships would impair or damage their own environment, human health, property or resources, or those of adjacent of other States.

In the actual implementation, the situation of vessels navigating both inland waterways and the sea was questioned. As the application scope of the BWM Convention does not make any reference to this situation, it can be assumed that the global regime will apply to an inland waterway vessel when it also sails the sea, provided that it is engaged in an international voyage.

The exclusion of domestic voyages from the application scope seems to lower the actual level of environmental protection that the BWM Convention aims to guarantee. The actual impossibility of removing HAOP once introduced, should guide Parties towards the application of BWM requirements even to domestic voyages and nothing in the BWM Convention prevents a State from doing so. On the contrary, the option for Parties of adopting more stringent measures, consistent with international law, is

explicitly outlined (IMO 2004b, Art. 2.3) and this should apply *a fortiori* to domestic voyages. Parallel legal international principles of prevention, precaution and responsibility might play a role in the States' decision in this respect. In the States' practice, several States considered prevention as crucial, extending the application of the BWM Convention to domestic routes (i.e., Australia, Brazil and France) (Lloyd's Register 2019). Even regional cooperation between States bordering, e.g., the Baltic and North seas, because of the especially vulnerable ecosystems, decided to apply at least the main BWM Convention regulations to ships that solely operate in these marine areas or alternating between the two of them, including both international and national routes (OSPAR/HELCOM 2020).

3.2 The BWM Standards for Discharge, Other Measures and Exceptions

The BWM Convention defines "ballast water management" as "mechanical, physical, chemical, and biological processes, either singularly or in combination, to remove, render harmless, or avoid the uptake or discharge of Harmful Aquatic Organisms and Pathogens within Ballast Water and Sediments" (IMO 2004b, Art. 1.3). "Ballast water" is "water with its suspended matter taken on board a ship to control trim, list, draught, stability or stresses of the ship" (IMO 2004b, Art. 1.2). The discharge of ballast water shall only be conducted in accordance with the provisions in the Annex to the BWM Convention and in line with the implementation schedule (IMO 2004b, Reg. B-3) of two different standards related to discharges, e.g., the "Ballast Water Exchange Standard" (Reg. D-1) and the "Ballast Water Performance Standard" (Reg. D-2) (see below). An "equivalent compliance" with the Annex is possible for pleasure craft used solely for recreation or

competition and for craft used primarily for search and rescue, less than 50 m in length overall, and with a maximum ballast water capacity of 8 cubic metres (IMO 2004b, Reg. A-5 and IMO 2005d). The relevant decision is up to the individual State, which has to take into account specific IMO Guidelines (IMO 2005d) providing precautionary practices to minimize the uptake, transfer and discharge of HAOP in ballast water and sediments.

The D-1 standard has been considered a short-term measure (Lakshmi et al. 2021) as ships will have to comply with it only until a certain date, when the phasing-in of the D-2 standard will apply. However, even if D-1 is an interim standard, the ballast water exchange will continue to be used in certain cases, i.e., when considered as a contingency measure for Port State Control or for prevention purposes. The implementation schedule of the performance standard is modulated according to certain criteria: the ships' age (year of construction), the ships' ballast water capacity (as defined) and the date of the International Oil Pollution Prevention Certificate (IOPP certificate) renewal survey (IMO 2004b, Reg. B-3).

Along the years, difficulties in the implementation of standards due to, i.e., shortages of dry-docking capacities to fit BWMS, generated in-depth discussions within IMO and the original timeline was reviewed with the result in 2018 to amend Regulation B-3. This amendment entered into force on 13 October 2019, *de facto* postponing the D-2 standard compliance date for existing ships, in some cases until 2024 (IMO 2018c).

(a) *The Ballast Water Exchange Standard (D-1)*

The Ballast Water Exchange Standard (BWE or D-1) (IMO 2004b, Reg. D-1) is a ballast water management method aiming at minimizing the risks of ballast water-mediated species introductions through water exchange in

the course of navigation. The exchange diminishes the probability of transferring HAOP between the ports of call. The D-1 standard is an interim method, as it will be (and partly was already) substituted by the D-2 standard according to Reg. B-3.

According to the BWM Convention, the D-1 standard is met when there is an efficiency of at least 95% volumetric exchange of ballast water. This result can be attained with different methods. The BWM Convention explicitly recognizes that using the pumping-through method, ships comply with the standard when pumping through three times the volume of each ballast water tank or, in case the pumping through is less than three times, when demonstrating that at least 95% volumetric exchange has been met (IMO 2004b, Reg. D-1.2). The BWM Convention also set the conditions of distance from nearest land and water depth for conducting BWE (IMO 2004b, Reg. B-4). In principle, it would be at least 200 nautical miles from the nearest land and in water at least 200 m in depth. In such cases when a ship is unable to satisfy these conditions, the exchange shall be conducted as far from the nearest land as possible, and in all cases at least 50 nautical miles from the nearest land and in water at least 200 m in depth. A ship shall not be required to deviate from its intended voyage, or delay the voyage, to comply with any particular BWE requirement.

BWE has to be conducted taking into account specific IMO guidelines (G6 Guidelines), last revised in 2017 to incorporate a Ballast Water Reporting Form (BWRF) (IMO 2017a). The G6 Guidelines recognize three valid methods for conducting the exchange (e.g., the sequential method, the flow through method and the dilution method) and address relevant safety issues that are involved by the exchange as well as non-compliance cases. BWRF is not a requirement included in the BWM Convention, however the form is a standardized way to provide information to the

port or coastal State which requires a ship, in a certain timeframe prior to entry into a port, offshore terminal or anchorage area, to provide specific information regarding the management of ballast water.

The consideration of specific vulnerabilities of Antarctica led IMO to approve specific Guidelines for the ballast water exchange through relevant routes within the geographical scope of the Antarctic Treaty area (IMO 2007a). Additionally, with a view to assist compliance with the D-1 standard, IMO, notwithstanding the absence of a correspondent provision in the BWM Convention, provided for uniform recommendations for design and construction of new ships in relation to BWE (IMO 2006a).

Many studies have been carried out on the actual efficacy of the exchanging process. In the open sea, the actual results in terms of HAOP presence and their transfer capacity may vary depending on the type of organisms considered (Molina and Drake 2016), i.e., exchange has not proven to sufficiently reduce potential threats of spreading of antibiotic resistance genes (Lv et al. 2020). In the open sea, different factors have been found to influence the exchange process, such as depth of water, season and the method of exchange. Mid-ocean exchange of ballast water has been demonstrated to be the preferred ballast water management method for ships lacking a proper BWMS (Shapoori and Gholami 2014). In general terms, scientific studies highlighted the need to combine the exchange practice with an onboard treatment, to gain a sufficient level of protection as BWE alone is, in many cases, not sufficient (Lakshmi et al. 2021).

BWE practice presents several safety issues for ships. The BWM Convention addresses the cases in which because of adverse weather, ship design or stress, equipment failure or any other extraordinary condition problem, the ship’s master may decide not to conduct the exchange if this would “reasonably” threaten the safety or

stability of the ship, its crew or its passengers (IMO 2004b, Reg. B-4). In these cases, relevant reasons must be recorded in the Ballast Water Record Book and the G6 Guidelines provide shipowners, operators, designers, classification societies and shipbuilders with relevant guidance on the operational aspects. However, the G6 Guidelines stress that, as specificities of the ship and of the voyage deeply influence the safety, it is essential that this aspect of the ship's operation is tackled both in the Ballast Water Management Plan and in the Ballast Water Record Book.

As not all sea areas and routes can meet the given BWE distance and depth parameters, the BWM Convention leaves to the port State the possibility of designating areas where a ship may conduct BWE, as appropriate in consultation with adjacent or other States (IMO 2004b, Reg. B-4.2). IMO G14 Guidelines assist port States in these areas' identification, assessment and designation (IMO 2006d). The designation often relates to small basins or areas shared by different States, and the guidelines provide with criteria and procedural steps for the relevant consultation and cooperation processes (e.g., identification of the potential sea areas, assessment of risks, principles on communication, monitoring and review). However, these designations remain an option for States (which may designate the areas) and the use of the areas seems to have a recommended character for ships (that *may conduct* BWE and could ask for the application of a number of safeguards, e.g., duty not to delay or deviate the voyage.) (IMO 2017b).

The implementation of this legal possibility resulted in different States' practice. BWE areas have been designated in the North Sea as a result of regional cooperation between coastal States and were endorsed by the OSPAR Commission, the governing body of the 1992 Convention

for the Protection of the Marine Environment of the North-East Atlantic (OSPAR 1992; IMO 2015). Information was shared with the Helsinki Commission, which includes States Parties to the 1992 Convention on the Protection of the Marine Environment of the Baltic Sea Area (HELCOM 1992), in a view of coordinating the approach with the Baltic even if, after thorough consideration of the possible natural spread, no Baltic exchange area was designated. A different attempt of regional institutional cooperation in Northeast Asia between State Parties (Republic of Korea and Japan) and non-Parties (at that time, China and Democratic People's Republic of Korea) did not end in an agreement, revealing problems related to competitive uses of the sea (e.g., fishing grounds) and the excessive burden for non-Parties (Cheol Yang et al. 2017). Regarding national practice, Parties would have to consider, in designating areas according to the G14 Guidelines, the existing legal and navigational constrains that may prevail on the risk assessment results, which is a non-binding tool (i.e., see the Canada practice in the Arctic areas, Goldsmit et al. 2019; Transport Canada 2021).

Difficulties in interpretation emerged at first on the legal consequences for ships where the depth and distance conditions for BWE were not met. It was unclear whether in this case ships would have been required to meet the D-2 standard ahead of its implementation schedule. IMO addressed and clarified the issue by providing a negative response (IMO 2017b), i.e., if the depth and distance requirement for BWE cannot be met, no ballast water exchange area is designated and D-2 does not apply yet to the vessel, it may result in a "do nothing" option for the ship. However, the reasons why ballast water exchange is not conducted should be in any case recorded in the Ballast Water Record Book.

Other uncertainties regarding the applicability of D-1 are linked to practical issues. Among them is the carrying out of a partial exchange as, according to relevant regulation, the ship should only exchange those tanks that it is able to fully exchange on its voyage. The G4 Guidelines outline that the tanks' partial exchange may encourage re-growth of organisms (IMO 2005a, 1.2.1.3) reinforcing the wording of the BWM Convention. Therefore, only full and complete exchanges of tanks shall be carried out. A partial exchange is possible for the ship, meaning that not all ship's ballast tanks are to be exchanged. When it becomes clear that the exchange of the next tank cannot be carried out completely, this tank should not be exchanged at all. The Ballast Water Management Plan should reflect this practical issue to clarify the procedure for an accurate exchange.

A connected practical issue concerns the case when the ship, while conducting an exchange, cannot comply anymore with the distance from land and/or the minimum water depth criteria, due to the geographical specifics of its position or because it has left a designated area for exchange. In these cases, as soon as it becomes clear that distance and depth criteria are not satisfied, no more tank exchange shall be started or, if it is in course, the exchange must stop. If for any tank the D-1 standard cannot fully be met, the exchange should not be commenced for that tank (IMO 2005a, 1.2.1.3). However, in the available time as many complete tanks (with ballast water to be discharged) as possible should be exchanged.

It must be stressed, that any circumstances during the exchange shall be recorded in the Ballast Water Record Book, including the reasons for not carrying out the exchange.

(b) *The Ballast Water Performance Standard (D-2)*

The Ballast Water Performance Standard (BWPS or D-2) requires ships to discharge ballast water with certain characteristics. According to the BWM Convention (IMO 2004b, Reg. D-2), ships shall discharge less than 10 viable organisms per cubic metre, greater than or equal to 50 µm in minimum dimension, and less than 10 viable organisms per millilitre, less than 50 µm in minimum dimension and greater than or equal to 10 µm in minimum dimension. Additionally, the discharge of certain indicator microbes (e.g., toxicogenic *Vibrio cholerae*, *Escherichia coli*, intestinal *Enterococci*) shall not exceed specified concentrations.

The BWM Convention does not require ships to treat ballast water on board. The discharge of ballast water might also occur to reception facilities, which in terms of compliance is considered as satisfying the D-2 requirement provided that the reception facility meets D-2 when discharging the water (IMO 2004b, Reg. B-3.6). However, there is not an obligation for port States to provide or make available such facilities but only to report to IMO—and only where appropriate, to other Parties—the information on their availability and location (IMO 2004b, Art. 14.11.b). Reception facilities are not legally defined, whereas they have to be designed taking into account the G5 Guidelines (IMO 2006b). In practice, discharge may occur in a treatment facility external to the ship located anywhere, i.e., on another ship or barge, on land, in or outside the port.

As alternatives to meeting D-2, other methods may be recognized as long as they achieve at least the same level of protection to the environment, human health, property or resources and are approved in principle by IMO MEPC according to a specific procedure (IMO 2004b, Reg. B-3.7 and IMO 2011a).

Outside from these cases, to meet the D-2 standard most ships will install onboard BWMS, which will have to be type approved according to the BWM Convention. BWMSs need to be tested according to the G8 Guidelines (IMO 2016a) and following the entry into force of the 2018 amendments, according to the mandatory BWMS Code (IMO 2018a). The term BWMS includes any system which processes ballast water such that it meets or exceeds the D-2 standard, including ballast water treatment equipment, all associated control equipment, piping arrangements as specified by the manufacturer, control and monitoring equipment and sampling facilities and excluding the ship's ballast water fittings (i.e., piping, valves and pumps) that would be required if the BWMS was not fitted.

The BWM Convention establishes general requirements for BWMS approval and recognition by States (IMO 2004b, Reg. D-3) addressing *inter alia* their safety for the ship, its equipment and the crew.

For BWMS making use of an "active substance," defined by the BWM Convention as "a substance or organism, including a virus or a fungus, that has a general or specific action on or against" HAOP (IMO 2004b, Reg. A-1.7), the responsibility of approval remains at IMO and shall follow an agreed procedure for approval, application and withdrawal. This process refers to basic and final approval of this active substance as evaluated by the Joint Group of Experts on the Scientific Aspects of Marine Pollution (GESAMP) through an *ad hoc* Ballast Water Working Group (IMO 2008b). The approval has to take into account the G9 Guidelines, which were updated multiple times (IMO 2005b, 2008a). Further, GESAMP-BWWG works according to their methodology, which was revised several times with the most up-to-date version being BWM.2/Circ.13/Rev.5 (IMO 2022d).

However, the approval process of all BWMS ends with a type approval of a national Administration and it was assumed that such an approval was of mutual recognition of other Administrations as an implicit issue (see below).

Uniformity of requirements for BWM approvals appeared to be an essential element as an onboard BWMS is part of the ships' design and equipment and different requirements for the entry in ports may heavily impact on navigation. In 2018, the need of uniformity led IMO to approve amendments to relevant regulations, e.g., Reg. A-1 on definitions and Reg. D-3 on approval requirements for BWMS which, following the example of other IMO conventions, e.g., MARPOL 73/78 and the International Convention for the Safety of Life at Sea (SOLAS 1974), established a Code for Approval of Ballast Water Management Systems (BWMS Code) as a mandatory instrument (IMO 2018a, d). Both, the amendments and the BWMS Code entered into force on 13 October 2019 and the issue of early movers was addressed agreeing that BWMS installed on or after 28 October 2020 shall be approved in accordance with the BWMS Code, while BWMS installed before 28 October 2020 were to be approved taking into account the G8 Guidelines, which applied starting from 28 October 2018.

Through this articulate system of obligations, States' attempt was to achieve as much as possible uniformity of the general requirements concerning BWMS approval, including design, installation, construction, testing, sampling analysis and evaluation, the BWMS Type Approval Certificates issuing and the reporting to IMO.

However, even if a BWMS approval would mean to screen-out those BWMS which would fail to meet the D-2 standard, the same approval does not ensure that a given system will work on all ships or in all situations. Nevertheless, the discharge must in any case comply with the D-2 standard throughout the life of the ship.

It can be mentioned that the adoption of the BWM Convention promoted a significant industrial development of commercial BWMS for onboard treatment that are in a continuous process of development. This regarded both ships built after the entry into force of the BWM Convention, that had to follow new construction schemes, and existing fleets, that had to retrofit BWMS. Significant burdens and costs, uncertainties linked to the different performance results provided by different combinations of technical solutions were among the factors that pushed the request of postponement of the D-2 standard application timeframe, leading to the amended implementation scheme (IMO 2018c). A recent scientific review of onboard treatment technologies identified different types of primary treatment, mechanical and chemical treatments having an effect on different types of HAOP and that could be variedly combined in BWMS with different results in terms of D-2 standard compliance (Lakshmi et al. 2021).

In connection with the anticipation by some shipowners of BWMS requirement, a question emerged on whether a ship which installed a BWMS ahead of the D-2 standard implementation schedule was required to comply with that standard. The question was solved by confirming that to have a BWMS installed on board does not result in the obligation for the ship concerned to comply with the D-2 standard beforehand nor affects the ships' implementation schedule.

Other questions arose during the implementation of the different G8 Guidelines versions regarding the identification of the date of BWMS installation. The 2016 G8 Guidelines edition clarified the reference to "installed" BWMS as the contractual date of delivery of BWMS to the ship and, in the absence of such a date, the actual date of delivery applied. In 2018 a unified interpretation was issued in this regard, revised in 2019 (IMO 2018e, 2019b).

Furthermore, several States doubted on the extent of the acceptance of foreign type approvals. The BWMS Code allows States to issue Type Approval Certificates based on testing carried out under the supervision of another State. Even though an already granted Type Approval Certificate may be accepted by another State, there is not an obligation to accept it. This interpretation seems to be confirmed by the repetition of the word “may” both in the 2016 Guidelines G8 (IMO 2016a, 6.6) and in the BWMS Code (IMO 2018d), implying that the decision lies within the competency of the acknowledging Administration. The BWMS Code describes how to handle type approvals already issued by other Administrations. A BWMS which in every respect fulfils the requirements of this Code may be approved by the Administration for fitting on board ships. Explicitly, for the installation on ships flying its flag, the Administration may accept a foreign type approval based on testing carried out under the supervision of a different Party. The acceptance of a Type Approval Certificate by a foreign Administration cannot automatically be assumed. Regional agreements or amendments of legislation might in the future lead to a situation where acceptance is the desired and enforced practice. However, the BWMS Code defines the internationally binding minimum requirements for the approval of BWMS that cannot be undermined, as set out in 6.1 of the Annex to the BWMS Code.

In case a State refuses to accept the type approval already issued by another State, consultations are to be organized and carried out (IMO 2016a, 6.9. and IMO 2018d). The aim of concerned Administrations would then be to find a mutually acceptable agreement. The BWMS Code facilitates a common understanding and interpretation, maintaining stakeholders’ credibility. Nevertheless, the consultation outcome remains open, and a secondary type approval might be refused if a common

understanding or interpretation cannot be found, even if the BWM Code clearly states that the objective is to find an agreement.

A last implementation point that needed clarification regarded the relation between the validity duration of the Type Approval Certificate and BWMS performance. The MSC.1/Circ.1221 on the validity for marine products aimed at eliminating uncertainties that may exist among Port State Control officers regarding Type Approval Certificates issued for marine products (IMO 2006a). The BWMS does not need to be renewed or replaced due to expiration of the relevant certificate (IMO 2006c) as it was also underlined in the BWMS Code (IMO 2018d).

(c) *More stringent or additional measures*

The BWM Convention stipulates that nothing in its text shall be interpreted as preventing a Party from taking, individually or jointly with other Parties, more stringent measures with respect to the prevention, reduction or elimination of the transfer of HAOP through the control and management of ships' Ballast Water and Sediments, consistent with international law (IMO 2004b, Art. 2.3). Further, additional or more stringent measures regarding ballast water control and management are options envisaged by different provisions of the BWM Convention and may be adopted by Parties, individually or jointly, through bilateral or multilateral cooperation.

Section C of the Annex entitled "Special requirements in certain areas" stipulates the power of Parties to determine further measures, consistent with international law, requiring ships to meet specific standards or requirements (IMO 2004b, Reg. C-1). To this end, a specific consultation with States that may be affected—adjacent or not—is mandatory before such standards or requirements are established (IMO 2004b, Reg. C-1.2). Additional measures

have to take into account relevant IMO guidelines, e.g., the G13 Guidelines (IMO 2007b), which recommend a proper assessment of the need of a measure, including an in-depth analysis of scenarios consequent to its adoption or not and of expected consequences and benefits. The nature of the measure has also to be properly investigated in terms of how this responds to the effective need resulting from the assessment. The consultation process gives (possibly) affected States the possibility to comment on the measure before it becomes legally binding, i.e., before relevant approval or entry into force. Consultations are conducted following an invitation to comment on a "draft assessment," "before the additional measures are decided upon" and affected States' responses may include recommendations (IMO 2007b).

To adopt the measure, the Party(ies) leading the initiative shall follow specific steps, including a communication to IMO of detailed information on the measure, include its description, the precise coordinates where it is applicable, the need and reasoning behind the measure, when possible, relevant expected benefits, as well as any arrangements to facilitate ships' compliance (IMO 2004b, Reg. C-1.2). This communication shall happen at least 6 months prior to the projected date of implementation.

The BWM Convention underlines that for additional measures or requirements Parties may obtain the approval of IMO, as appropriate and to the extent this is required by customary international law as reflected in the LOS Convention. This may happen when the measures are provided for in other legal instruments, i.e., routing and reporting measures according to SOLAS Convention and to the Convention on the International Regulations for Preventing Collisions at Sea (COLREG) (SOLAS 1974; COLREGs 1972) and designations of Particularly Sensitive Sea Areas according to IMO Resolution A.982(24) (IMO

2005c). The G13 Guidelines further specify that the communication to IMO shall address the MEPC and include *inter alia* the legal determination upon which each additional measure is submitted. It is worth noting that the period of 6 months before the measure adoption is not consistent with the 12 months period required by the LOS Convention for the approval of shipping measures in clearly defined areas of the Coastal States' Economic Exclusive Zone (LOS Convention 1982, Art. 211.6).

Additional measures may be temporary, shall not compromise safety and security of the ship and cannot in any circumstances conflict with any other convention with which the ship must comply. Parties shall endeavour to make available all appropriate services needed to implement the measure, i.e., through notification to mariners of areas where specific measures are in force or of alternative routes or ports to ease the burden on the ship. The G13 Guidelines also provide guidance on additional measures whenever emergency situations occur in relation to ballast water operations.

A comprehensive review of additional measures adopted by Parties is not available. However, examples of States' practice in this regard includes the identification of "areas to be avoided" established for the purposes of banning ballast water uptake, discharges or exchanges (i.e., Panama, Chile, Canada and Brazil) (Lloyd's Register 2019).

Among the additional measures are warnings to mariners concerning ballast water uptake in certain areas, detailed in a different provision of the same Section C of the BWM Convention (IMO 2004b, Reg. C-2). These notifications address directly mariners of areas under the jurisdiction of the Port/Coastal State where ships should not uptake ballast water due to known conditions (i.e., algal blooms and outbreaks, infestations and presence of HAOP or sewage outfalls). As warnings do not *per se* imply a

mandatory character for ships addressed, they could be adopted as mandatory requirements when planned and implemented according to Reg. C-1 and relevant parts of the G13 Guidelines.

(d) *Exceptions and exemptions: gaining knowledge on national and regional environmental features*

These subjects are covered by BWM Convention Articles A-3 Exceptions regarding, e.g., ships safety and the same location as well as Article A-4 Exemptions for, e.g., risk-assessment based exemptions from BWM and the same risk area (see also IMO 2014c).

Exceptions

The Annex to the BWM Convention stipulates a number of exceptions to the application of certain requirements. Exceptions may refer to the requirements of, e.g., Regulation B-3, the D-1 and D-2 standards, as well as to measures adopted by a Party pursuant to Article 2.3 and Section C of the BWM Convention, e.g., more stringent measures consistent with international law or special requirements established for certain areas (IMO 2004b, Reg. A-3). Exceptions apply in each of the following cases: (1) when uptake or discharge of ballast water and sediments is necessary for the purpose of ensuring the safety of a ship in emergency situations or saving life at sea; (2) when the accidental discharge or ingress of ballast water and sediments results from damage to the ship or its equipment, provided that all reasonable precautions for preventing or minimizing the discharge have been taken; (3) when the uptake and discharge of ballast water and sediments aim at avoiding or minimizing pollution incidents from the ship; (4) in case of uptake and subsequent discharge on the high seas of the same ballast water and sediments; (5) in case the discharge of ballast water and

sediments from a ship is at the same location where the whole of that ballast water and sediments originated and provided that no mixing with unmanaged ballast water and sediments from other areas has occurred.

While those A-3 Exceptions, among those listed, addressing safety and emergency situations are only temporary and limited in time, the other exceptions' cases may apply permanently to ships operating only in the high seas or in the "same location," theoretically opening possibilities of circumventing the global requirements. No further definition of the "same location" is provided by the BWM Convention. Only the G3 Guidelines, while addressing ballast water management equivalent compliance for smaller pleasure and search and rescue crafts, refer to "same location" as having the meaning of "same harbour, mooring or anchorage" (IMO 2005d, 4.5.2).

In the absence of a legal definition of "same location" directly applicable to exception cases, the geographical extension of the relevant exception opened a variety of Parties' interpretations based on different scientific concepts that may hypothetically arrive at including a whole sea. The inappropriateness of too extensive interpretation approaches to prevent the actual risks of HAOP secondary transfers was stressed in literature, together with the need of global guidance aiming at the uniform implementation of the relevant BWM Convention provision (David et al. 2013b). Several studies focused on the practical consequences in terms of HAOP transfers of the application of the exception (Gollasch and David 2012; David et al. 2013b) and recent case studies showed that even different terminals of the same harbour may present in practice high risks (Vuosaari harbour in Finland, Outinen et al. 2021). Based on scientific data, same studies suggested that the application of the same location-based exception should be limited to the smallest feasible areas within a harbour, such as a single anchorage or terminal,

further restricting the G3 Guidelines definition (Outinen et al. 2021).

Parties did not agree on an interpretation on the matter; however in IMO's practice the definition provided by the G3 Guidelines has been considered as the main reference. In any case the "same location" exception clause would have to be interpreted by States considering current status and principles of international law and, in particular, in light of relevant principles of the Vienna Convention on the Law of Treaties (VCLT 1969) by interpreting terms in good faith, in accordance with their ordinary meaning in their context and in the light of the treaty objectives and purpose (VCLT, Art. 31 and 32). Consequently, the same location exception would have to be applied in light of the biodiversity protection duties (CBD 1992), of the precautionary approach as set out in Principle 15 of the Rio Declaration on Environment and Development and in the relevant IMO resolution (IMO 1995) as well as of the BWM Convention broader objectives of prevention, minimization and ultimately elimination of risks arising from HAOP transfer. Currently, there is no comprehensive review available on the Parties' practice in relation to the application of exceptions.

Exemptions

The BWM Convention also stipulates a detailed regime on A-4 Exemptions (IMO 2004b, Reg. A-4). While exceptions automatically exclude from the requirements all ships falling under the categories as listed, exemptions are the result of a case-by-case decision taken by Parties and can be granted to ships or routes upon a specific request. Exemptions may be granted in relation to the application of D-1 and D-2 standards (e.g., any requirement in Regulation B-3) or to the application of Parties' additional measures (e.g., adopted according to Regulation C-1).

Explicit mandatory conditions for Parties in granting exemptions are: (1) exemptions have to apply to a ship(s) on a voyage(s) between specified ports or locations or to a ship which operates exclusively between specified ports or locations; (2) exempted ships do not have to mix ballast water or sediments other than between the ports or locations specified; (3) exemptions have to be effective for a maximum period of 5 years subject to an intermediate review; (4) exemptions have to be granted based on the guidelines on risk assessment developed by IMO, i.e., the G7 Guidelines (IMO 2017c). Exemptions may be granted in waters of jurisdiction and become effective only after its communication to IMO and circulation to Parties. The Party granting an exemption shall determine and consult any State that may be adversely affected, with a view to resolving any identified concerns. Exemptions granted shall not impair or damage the environment, human health, property, or resources of adjacent or other States.

The G7 Guidelines were firstly adopted in 2007 and were superseded in 2017 by the version currently effective (IMO 2017c). The G7 Guidelines aim at the worldwide consistent application of the exemption regime by providing the main criteria to satisfy in undertaking a scientifically robust Risk Assessment (RA). An RA in line with the G7 Guidelines is a mandatory precondition for granting exemptions. In this regard the G7 Guidelines outline three RA methods (e.g., environmental matching RA, species' biogeographical RA and species-specific RA) which can be used either individually or in combination, enabling Parties to distinguish between unacceptable high-risk scenarios and acceptable low-risk scenarios descending from an exemption.

The granting of exemptions may be possible only based on an appropriate knowledge of the main features of the environments that are being connected through the ship's route. While the BWM Convention only mentions HAOP, the

G7 Guidelines include additional definitions of “Non-Indigenous Species,” as any species outside its native range, whether transported intentionally or accidentally by humans or transported through natural processes (IMO 2017c, 4.11), “Cryptogenic” as species that are not demonstrably native or introduced to a region (IMO 2017c, 4.5), as well as of “target species” as species identified by a Party that meet specific criteria indicating that they may impair or damage the environment, human health, property or resources and which are identified for a specific port, State or biogeographic region (IMO 2017c, 4.13). NIS, Cryptogenic and target species are subsets of HAOPs. All RA-envisaged methods imply a deep knowledge, both in the donor and recipient ports/biogeographic regions, of relevant environmental conditions and of the HAOP presence, native range, source and conditions for survival.

The identification of the procedures for granting (and withdrawing) exemptions is up to Parties as ballast water recipient port State(s), however the G7 Guidelines tackle key procedural elements. According to the G7 Guidelines, Parties are free to decide whether to undertake RA themselves or require the shipowner or operator to perform it. In any event, the Party granting an exemption is legally responsible for “evaluating the risk assessment, verifying the data and information used, and ensuring the risk assessment is conducted in a thorough and objective manner in accordance with” the G7 Guidelines (IMO 2017c, 7.2). The G7 Guidelines leave to Parties the choice in the desired combination of methods to evaluate the extent of risk, at the same time addressing the issue of the level of uncertainty inherent in the evaluation. The assessment must consider uncertainty, that when found at a “high” level may be sufficient itself to deny the exemption and, from the opposite perspective, the absence of, or uncertainty in, information should not be considered as a reason to grant an exemption. Not being in accordance

with the G7 Guidelines is *per se* considered as a reason to reject an application, subject to the duty of providing appropriate reasons. However, “once the level of risk and the extent of uncertainty have been assessed, the result can be compared to the levels a Party(s) is willing to accept in order to determine whether an exemption can be granted” (IMO 2017c, 6.5.9).

The G7 Guidelines also describe some elements influencing the duration of the exemptions that can be considered as a non-exhaustive case list. An approved exemption may be suspended, revoked or withdrawn. Non-compliance during the exemption period should result in prompt suspension or revocation. If the actual risk associated with a voyage has increased substantially since the RA was conducted, the exemption should be withdrawn. As further examples are emergencies or other high-risk situations as outbreaks, incursions, infestations, or proliferations of HAOP populations which are likely to be taken up in ballast water, whether they have been notified to mariners by the coastal State or not (e.g., harmful algal blooms) (IMO 2004b, Reg. C-2 and IMO 2017c, 10). The choice between suspension and withdrawal appears to be linked to the persistence in time of the conditions of the arisen risk.

According to the G7 Guidelines, the exemption approval may include restrictions within its time of validity (i.e., seasonal and time-specific) (IMO 2017c, 7.5). Since the time the exemption is granted and over its duration the port State shall ensure ships do not mix ballast water or sediments from other areas and may require the evidence of the specific measures undertaken to comply. An intermediate review is recommended within 12 months from the exemptions’ approval and in any circumstances no later than 36 months after permission is granted. In any case a recipient port State may require several reviews to

be taken, even if the G7 Guidelines recommend not to exceed an annual frequency.

G7 Guidelines though does not directly define RA decision model (DSS), hence RA for exemptions have been studied for years (David 2007; David et al. 2015) to provide DSS to support exemptions implementation in certain areas or regions. RA DSS were developed as general models (David and Gollasch 2014; David and Gollasch 2015), and for Baltic (David et al. 2013a; David and Gollasch 2016) and Adriatic seas (David and Gollasch 2016) specific implementation. They may be considered for use elsewhere, with adaptation when needed.

The implementation of the exemptions' regime has been controversial. Since 2014, political and technical considerations highlighted contradictions. Some States noted that exemptions were needed for international routes between very close ports with a longstanding and intense shipping traffic while domestic voyages connecting distant locations presenting a high risk of HAOP transfer and establishment were not subject to the global regime (Stuer-Lauridsen and Overgaard 2014; IMO 2014b). The exemptions' regime also raised questions on its impact over the short shipping sector, whose development in the EU was supported by specific policy measures as a mean to contrast climate change (IMO 2014b). Costs of sourcing the data to underpin an RA for each ship and route were considered prohibitive for well-developed local trading patterns, being able to effectively exclude the exemptions option for certain traffic segments of the short shipping sector, e.g., ferries and supply vessels (Stuer-Lauridsen and Overgaard 2014; Stuer-Lauridsen et al. 2018; IMO 2014a). These considerations together with the assumption that short sea voyages within areas of HAOP natural dispersion may be unlikely to greatly alter the consequences from the natural transfer of potentially harmful and invasive species led to elaborate area-based

approaches, namely the Same Risk Area (SRA). The SRA proposal found support of those Parties and organizations which looked at SRA as a practical criterion to secure acceptable low risk operation of exempted ships through an RA on large and connected areas, without need to amend the BWM Convention and useful to address the shipping problems in overlapping or adjacent marine regions (IMO 2014b, c).

After in-depth discussion, IMO reconciled SRA within the G7 Guidelines through 2017 amendments, defining SRA as "an agreed geographical area based on a completion of a risk assessment carried out in line with G7," typically applying a species-specific assessment and subject to consultation and agreement between States that may be affected. In the G7 Guidelines, the extent of an SRA may be derived from the modelling of the extent and directionality of natural dispersal of target species between connected locations of relevant populations. The relevant assessment will be considered as low risk if target species are already present in all the selected ports or locations or have a high probability, based on validated models, of establishing throughout the SRA by the process of natural dispersal within the agreed time window (IMO 2017c, 6.5.6). The G7 Guidelines failed to outline a specific standardized protocol and methodology for SRA, neither these instruments are available in literature as modelling methods differ depending on the biogeographical region assessed nor the detailed distribution data of HAOP are available (Outinen et al. 2021).

The advantages of the area-based approach (e.g., the accounting for an ever-present component in the risk of invasive species, the assessment of an area rather that multiple isolated points, the suitability for Administrations as a decision-support tool to grant area-based exemptions to ships trading in short sea shipping, simplicity for operators in checking through models at an initial stage the

feasibility of the exemption process before undertaking the full process) have been underlined by some authors together with technical limitations (Stuer-Lauridsen et al. 2018). More recent case-studies emphasized how in line with the G7 Guidelines the SRA models need to be integrated with significant elements and data and result in a small proportion of low-risk cases (Outinen et al. 2021). The key findings of this work included that (a) exceptions and exemptions should by no means be considered as common options for ballast water management, instead these should be rare cases, (b) the primary BWM Convention objective to mitigate HAOP introduction with ballast water should not be undermined and (c) new HAOP introductions are extremely difficult to predict so that all exceptions and exemptions should be viewed with caution and continuously be re-evaluated.

As examples of the Parties' practice with regard to SRA are the three domestic SRAs identified by Australia in Victoria (Port Phillip), Queensland (Great Barrier Reef) and South Australia (Spencer Gulf and St Vincent Gulf) (Australian Government 2017) and the designation as an SRA by the Swedish and Danish authorities of Öresund. In the latter case, SRA was based on a conservative approach in interpreting the results of extensive model studies (Hansen and Christensen 2018) and exemptions have been granted to a number of applicant ferries operating between the ports of Helsingborg in Sweden and Helsingør in Denmark (IMO 2022a).

Notwithstanding global specifics, the use by a Party of the possibility to exempt routes and vessels still may affect the (protected) interests of other Parties and States, whether adjacent or not. The BWM Convention requires Parties to identify and consult those that may be adversely affected by exemptions, with a view to resolving identified concerns. The G7 Guidelines provide with general advice on States' cooperation—including communication, technical

assistance and regional cooperation—and further outline the consultation procedures (IMO 2017c, 8). With a slightly different wording, the G7 Guidelines require Parties to consult any State that may be adversely affected from any exemptions that may be granted. Time given to affected States to consider proposed exemptions must be sufficient to consent a careful examination of the information included in the invitation. It can be concluded that the consultation must address all and every State possibly affected, prior to the exemption approval. As regards the consultation feedbacks, consulting States may ask providing comments and/or conditions or not. Consulted States that do not support the granting of the exemption(s) should provide appropriate reasons as well as clearly identify any conditions or limitations that would enable them to support an exemption. No further guidance on how to resolve a permanent disagreement between consulting Parties and affected States is provided, and therefore possibly the ordinary remedies provided by international law should apply.

A successful example of States' cooperation concerning exemptions, within and between marine regions, concerns two European marine areas, e.g., the Baltic Sea and the North-East Atlantic Ocean. In both regions, coastal States have in place a longstanding legal cooperation framework for environmental protection purposes, including against shipping-sourced pollution. After a Ministerial declaration, relevant regional organizations agreed on common guidelines and on a Joint Harmonised Procedure (JHP) on the granting of exemptions, giving application Art. 13(3) of the BWM Convention. Until 2024, the JHP is planned to be implemented in a flexible and practicable way to gain experience and to enable its further development and improvement. The JHP guides bi- or multi-national evaluations of applications for exemptions, driving Parties bordering the marine areas towards consistency of

assessments within the same marine area. Harmonization includes the information and data gathering processes—through common sampling and port survey protocols as well as common target species—the assessment methodology—by identifying the RA criteria to apply—and the evaluation scheme—using a single RA online automated decision support tool (OSPAR/HELCOM 2020). The JHP is based on the agreement between donor and recipient ports that jointly keep updated and under review its technical elements (Outinen et al. 2021).

As the regional procedure does not substitute the role of the recipient port State(s) in the process of assessing applications and granting exemptions, national authorities carry out an in-depth review of the specific application case. However, the JHP also uniforms some aspects of the administrative procedure, i.e., authorities to inform and timing to approach the authority. The appointed authority in the port State(s) consults with other concerned States and considers the specific conditions for the route, for data availability or for the RA, notifying the applicant on the terms for the application. If exemptions have been granted on the route before, the Party should still consider the specifics for other ships applying for an exemption on the same route.

The JHP also identifies at regional level other essential elements of exemptions. Exemptions cannot be granted by the Administration for a time period longer than the validity of port surveys, which is 5 years. The approval may contain specific restrictions or terms for uptake and discharge, e.g., regarding ballast water volumes, locations and seasonal or periodical adaptions when some risks factors may increase. The approval may apply only for specific terminals located in the same port or to specific periods of the year. Mitigation measures to decrease high risk scenarios may be included as conditions to an exemption decision. Intermediate reviews should be based on any new

information and may include a review of the ship's voyages (e.g., on the basis of log book records). Exemptions' withdrawals may be based on route and ship specifics, on the acceptance for increased risk during the exemptions period and on possible mitigation and contingency measures to be applied (e.g., restrictions on ballast water uptake/discharge in certain areas, limitations of ballast water volumes, use of permanent ballast water). Temporary deviations from the exemption route, e.g., for dry-docking, maintenance or repair are also considered.

Apart from the regional cooperation on exemptions, information on States' practice is available through data voluntarily provided by flag States within the Experience Building Phase (see above). Over a total of 15,700 ships, 1.2% have been exempted in accordance with Regulation A-4. Figures provided by recognized organizations report a smaller percentage (0.03%) (IMO 2022h)

3.3 The Paperwork and the Surveys Regime

(a) *Ballast Water Record Book (BWRB)*

Each ship to which the BWM Convention applies and which flies the flag of a Party, regardless of its size, must carry a Ballast Water Record Book (BWRB) on board (IMO 2004b, Reg. B-2). In the case of an unmanned ship under tow, the BWRB may be kept on the towing ship. Minimum BWRB mandatory information is outlined in Appendix II of the BWM Convention. BWRB may be an electronic record system or may be integrated into another record book or system.

Ballast water operations must be recorded without delay. In the event of any ballast water discharge to a reception facility or of any applicable exception or exemption granted, or in case of any accidental or exceptional discharge not otherwise exempted, a

corresponding entry in the BWRB shall be made describing any circumstances and reasons for the discharge.

Each BWRB entry shall be signed by the officer in charge of the operation concerned. Each completed page shall be signed by the master. All entries shall be in a working language of the ship and at least include a translation into one of English, French or Spanish languages. The entry made in the official national language of the flag State shall prevail in case of a dispute or discrepancy. BWRB entries shall be maintained on board the ship for a minimum period of 2 years after the last entry has been made and thereafter in the company's control for a minimum period of 3 years.

Minimum requirements of the BWRB include (IMO 2004b, Appendix II) the period of use (from date to date) and ship's information: ship name, IMO number, gross tonnage, flag, total ballast water capacity in cubic metres, a statement that the ship is provided with a BWM Plan and a diagram of the ship that indicates the ballast tanks.

Further minimum requirements of the BWRB relate to mandatory entries during the following ship operations: when ballast water is taken on board, whenever ballast water is circulated or treated for ballast water management purposes, when ballast water is discharged into the sea or to a reception facility, in case of any accidental or other exceptional uptake or discharges of ballast water. Entries include any additional operational procedure and general remarks. For each occasion, minimum information to be provided is accurately detailed (IMO 2004b, Appendix II, 3.1 to 3.6) and partial or inaccurate records would not be sufficient to comply with the requirements. Nevertheless, some of the information required is recognized as being estimations, e.g., the accuracy of estimated volumes of ballast water in cubic metres is left to interpretation (IMO 2004b, Appendix II, 3.1.2, 3.2.2, 3.3.2, 3.4.4, 3.5.3 and 4).

References to mandatory information to be recorded in BWRB are in some cases explicitly mentioned by the relevant provisions of the BWM Convention: this is the case of exemptions granted (IMO 2004b, Reg. A-4.4) as well as of the reasons for not conducting BWE when this would be required (IMO 2004b, Reg. B-4.5). Regarding this latter issue circulars and guidelines require relevant entries too (IMO 2017a, b).

During the BWM Convention implementation, some questions arose on the exact shape and format of BWRB. These questions were particularly relevant in light of the State controls on ships' compliance, the onboard documentation representing a crucial component of inspections of any shipping treaty. Officers duly authorized by a Party may inspect BWRB on board any ship while in port or offshore terminal and make a copy of any entry. Port State Control Officers (PSCOs) may also require the master to certify that BWRB copy is a true copy. The certified BWRB is an admissible evidence in any judicial proceeding. The inspection operations shall be performed (in any case) as promptly as possible without causing the ship's undue delay (IMO 2004b, Reg. B-2.6). BWRB shall be kept readily available for inspection at all reasonable times.

A question emerged regarded whether the item numbers included in the Appendix II entitled "Form of Ballast Water Record Book" would have need to be referenced in BWRB and considered as part of the minimum requirements. The discussion opens the question on whether Appendix II contains a mandatory form in all its aspects, including the numbering. The descriptive wording used in the Appendix to specify the various entries, however, as well as the mentions to the eventual need of an "approved format" for BWRB (IMO 2014d, 2.2.1.4) might lead to consider the form as a sample scheme of how the minimum mandatory requirements and respective entries may be recorded. This view is supported by consideration of the presence in other

shipping treaties, e.g., the MARPOL Convention (MARPOL 73/78, Annex I, Appendix III) of explicit references to the mandatory character of the record book.

A different question regards the record book physical format. During inspections, officers may find that records of the operations are in the form of a loose-leaf collection or booklet, maybe with a self-made layout. This might not be considered as a violation as long as all the legal requirements are satisfied, e.g., minimum required information is included, every completed operation is signed by the officer in charge and every page is signed by the master. The compliance shall be assessed on a case-by-case basis.

Some uncertainties regarded BWRB in electronic format, as it is explicitly allowed without further details on its shape or management. Doubts raised on the signing modalities. Whereas it might be easier to set an electronic signature behind each recorded operation, the technical means to have each page of the electronic BWRB signed by the master are less immediately available. In any case, if a printout is presented to control officers, the pages must appear signed. Also, the records in the electronic system need to be readable at any time and during the period as defined. It might be helpful to look at the two different digital signature mechanisms of signing the record of operation and verifying the signed record of operation as well as at the access control and monitoring mechanisms.

In any case, IMO Guidelines for Port State Control retrieved to the use of PSCOs the specific aspects of the BWRB to be controlled (IMO 2014d, 2.2.1.4).

The findings of 2022 EBP indicated that most frequently reported deficiencies (greater than 70%) during port State control were related to BWRB (IMO 2022h). Taking the occasion of IMO approval of the Data Gathering and Analysis Plan (DGAP) some shipping organizations underlined differing interpretations provided by

Administrations, port State Authorities, class societies and third-party auditors and inspectors when examining ballast water activities recorded in the BWRB (INTERTANKO 2020). The lack of a coding system in analogy of the Oil Record Book was stressed as causing this uncertainty. Several ballast water operational scenarios were identified as in need to be more properly tackled by the BWRB, i.e., the absence of distinction of the method of BWE being used by the ship, distinctions between common ballasting operations, the ballast water treatment recording during ballasting and/or deballasting, the single tanks consideration and the handling and disposal of sediments.

Proposals for a revised BWRB, analogue to the Oil Record Book model, integrating the ballast log details and based on current shipboard operational procedures are currently under discussion (IMO 2021b, 2022b). Future amendments should ease the work of crews, PSCOs and surveyors, through improving accuracy and unambiguous records by taking into consideration operational practices. The most recent meeting of MEPC (December 2022) addressed BWRB amendments as the current form did not provide sufficient clarity and this had an impact on the operation of ships (IMO 2022e, f). The proposed amendments were seen as useful to provide detailed information and some modifications should not be mandatory but their usage might be recommended on a voluntary basis. Their adoption is on the MEPC agenda together with proposals relating to a new electronic Ballast Water Record Book (eBWRB) (IMO 2022f, g h2023).

(b) *Ballast Water Management Plan (BWMP)*

Each ship to which the BWM Convention applies and which flies the flag of a Party, regardless of its size, shall have on board and implement an approved Ballast Water Management Plan (BWMP), specific to the ship, describing

the ballast water process and procedures implemented on board (IMO 2004b, Reg. B-1). The plan has to be approved by the ship's Administration, meaning the Government of the State under whose authority the ship is operating (IMO 2004b, Art. 1.1), taking into account IMO G4 Guidelines, approved in 2005 and amended in 2018 (IMO 2005b, 2018f). The amendments regarded the possibility to include in BWMP contingency measures in case a ship is unable to manage ballast water in accordance with its approved plan. As BWRB, BWMP shall be written in the working language of the ship, and translated into English, French or Spanish languages.

The minimum mandatory content of this ship-specific plan includes: the safety procedures for the ship and the crew, associated with ballast water management; the actions to be taken to implement the ballast water management requirements and supplemental practices, the procedures for the disposal of sediments at sea and to shore, the procedures for coordinating shipboard ballast water management that involves discharge to the sea with the authorities of the State into whose waters the discharge has to take place; the reporting requirements; the designation of the officer on board in charge of ensuring that the plan is properly implemented.

The ship's BWMP is an important element of the ballast water management regime. The surveys to issue International Ballast Water Management Certificate (IBWMC) shall verify that the BWMP and any associated structure, equipment, systems, fitting, arrangements and material or processes are fully compliant (IMO 2004b, Reg. E-1.1.1).

BWMP shall also include the provisions to remove and dispose sediments from spaces designated to carry ballast water, a requirement for all ships (IMO 2004b, Reg. B-5).

No specific implementation aspects have been formally raised by States to IMO regarding BWMP. However,

available data voluntarily provided by flag States to the EBP on 15,700 approved BWMP indicated that 71.6% include ballast water exchange procedures and 49.2% involve contingency measures. Similar data provided by recognized organizations reported on a total of 25,995 approved BWMP a lower percentage of ships (57.2%) including ballast water exchange in accordance with D-1 procedures while 7.4% including contingency measures. Two PSC Memorandums of Understanding (MoUs) submitting data to EBP identifying deficiencies related to the BWM Convention, respectively, from 1 November 2020 to 31 October 2021, and from 1 November 2017 to 31 November 2021, showed similar results between each other and identified the BWMP as the second of the four main areas of deficiencies registered, after BWRB. The information was consistent with the one provided by flag States (IMO 2022h).

A specific obligation related to BWMP is directly posed by the BWM Convention on officers and crews. Literally, these individuals shall be familiar with their duties in the implementation of ballast water management on the ship on which they serve, and, appropriate to their duties, with the ship's BWMP (IMO 2004b, Reg. B-6). As Parties are the legal subjects assuming the treaties' obligations, it can be assumed that each Party should be responsible for the implementation of this provision, at least requiring ships' flying their flags to organize and implement appropriate information and training. Guidelines address specificities of the training needed in relation to many obligations, i.e., in relation to BWRB, the G7 Guidelines outline the need of appropriate training for ship's masters and crews on instructions on the BWMP and the completion of relevant records in this regard (IMO 2017c). IMO MEPC approved a new output on "Development of training provisions for seafarers related to the BWM Convention" in its post-biennial agenda, involving in the work the Sub-Committee

on Human Element, Training and Watchkeeping (HTW) as the associated organ (IMO 2018g).

(c) *The International Ballast Water Management Certificate (IBWMC) and surveys' requirements*

Differently from the BWRB and the BWMP, only ships of 400 gross tonnage and above to which the BWM Convention applies shall have on board an International Ballast Water Management Certificate (IBWMC), subject to a detailed survey regime (IMO 2004b, Section E). Floating platforms, FSUs and FPSOs are excluded from the certification requirement. However, ships engaged only in domestic voyages to which the BWM Convention does not apply may request the issuing of a certificate, provided that the recognized organization perform relevant surveys. Even if certification and survey procedures are not required for certain ships, Parties shall establish appropriate measures to ensure that the applicable provisions of the BWM Convention are complied with. The IBWMC may be issued only to Parties.

IBWMC has been the subject of a unified interpretation in line with the amendments to the BWM Convention and relevant guidelines which clarified the mention to the dates referred therein (IMO 2019b).

The form of the IBWMC is provided (IMO 2004b, Reg. E-4 and Appendix I). The certificate shall be drawn up in the official language of the issuing Party, and a translation in English, French or Spanish language shall be included. Conditions on duration and validity of IBWMC are detailed as well as the survey's regime which has been amended in 2018 (IMO 2018b) entering into force in 2024.

3.4 Port State Controls

PSC regime provided by the BWM Convention introduces control and inspection options, both technically and legally

challenging (IMO 2004b, Art. 9–12).

PSC actions for compliance with ballast water have to be conducted in light of Art. 3.3 prescribing that Parties shall apply the BWM Convention requirements as may be necessary to ensure that no more favourable treatment is given to ships of non-Parties to the Convention. The principle in question is enshrined in MARPOL 73/78 and other IMO conventions and has been included in many PSC MoUs (Paris MoU 1982). In the BWM Convention the provision has also been strengthened in relation to the duties of PSCOs who should apply the same requirements with respect to ships of non-Parties (IMO 2014d, 1.3.4).

Alike other IMO instruments, the BWM Convention resumes the legal principle of undue delay of ships, drawn from the LOS Convention and supported by a constant legal practice at global level (IMO 2004b, Art. 12; LOS Convention 1982, Art. 226). According to relevant provisions, Parties shall make all possible efforts to avoid causing ships any undue detainment or delay because of surveys, inspections, and control actions. Otherwise, the ship would be entitled to compensation for any loss or damage suffered. Sediment reception facilities also shall operate without causing undue delay to ships without mention to any direct consequence in terms of compensation (IMO 2004b, Art. 5).

PSC inspection activities are identified in detail. While in a port or offshore terminal of a Party, foreign ships may be inspected by officers duly authorized (IMO 2004b, Art. 9). A first level of inspection has to be limited to (a) the verification on the presence on board of a valid IBWMC, (b) the inspection of the BWRB and (c) a sampling of ships' ballast water, in accordance with IMO Guidelines. On PSC, IMO approved two sets of guidelines, the Guidelines on port State control (IMO 2014d) and the Guidelines for ballast water sampling (G2 Guidelines) (IMO 2008c). In addition, IMO developed and revised multiple times a

guidance document providing additional information regarding ballast water sampling and analysis (IMO 2020).

The 2014 Guidelines on PSC provide basic guidance for the conduct of inspections aimed at verifying compliance of ships to which the BWM Convention applies. The main compliance provisions and exceptions to be checked are listed and the ballast water management regime is further described (IMO 2014d, 1.3.2 and 1.3.3). Differently from the BWM Convention, PSC procedure envisages a four-stage inspection. An initial inspection focuses on documentation and the presence of a trained and designated ballast water officer. A more detailed inspection stage starts when there are clear grounds for believing that the condition of the ship or its equipment does not correspond substantially with the particulars of IBWMC or the master or the crew is not familiar with essential shipboard procedures relating to ballast water management or has not implemented them. At this stage, the controls address the operation of BWMS according to BWMP as well as the self-monitored operational indicators included in the procedures of type approval. A third stage of inspection envisages sampling relying on indicative analysis, to identify whether the ship is meeting the D-2 standard or if a detailed analysis is necessary to ascertain compliance. A fourth stage incorporates a detailed analysis to verify compliance with the D-2 standard. Ballast water sampling and analysis can count on the practical and technical guidance provided by the G2 Guidelines.

Whereas the control of the onboard documentation corresponds to a common practice for PSCOs, the sampling of ballast water raised several technical difficulties and corresponding legal uncertainties. Among the problems brought by practice, the time needed for analysis of samples is a potential issue to interfere with the port States' obligation of not unduly delaying the operation, departure or movement of the vessel (IMO 2004b, Art. 12).

Uncertainties emerged also regarding sampling requirements for the control of the D-1 and D-2 standards' compliance, a serious concern both for the shipping industry and for the port State reliability. Among the problems emerged were the technical challenges in demonstrating D-1 standard compliance through parameters used in isolation, the influence of the physical sampling point on accuracy of estimates of organism concentrations when checking D-2 standard compliance and the need to strengthen PSC with specific and significant investments in training as well as external expertise.

The G2 Guidelines addressed several of these concerns by providing guiding principles aiming at improving consistency of Parties' approaches including on sampling protocols for testing compliance. Furthermore, the potential of indicative ballast water discharge analysis for PSC to establish whether a ship is potentially compliant or non-compliant is underlined, also as a tool for PSCOs in the adoption of immediate mitigation measures avoiding any additional impact from a possible non-compliant discharge. Specific ballast water sampling kits have been recommended as minimum equipment for PSC. Advice is also provided on the chain of custody records for the samples collected, e.g., a complete record of those handling the sample from the time of the sampling onwards, the sampling date, ship identification, sample identification code, dates and time, the reason for sample transfer and the integrity of the sample on transfer.

Ballast water sampling and analysis are crucial aspects for uniformity and efficiency of compliance controls and have been the subject of further technical guidance through recommended methods, approaches and protocols included in specific circulars, recently updated (IMO 2020).

On the same aspects ISO standardization work is also progressing through the ongoing preparation of two

standards, e.g., ISO 11711-2, ships and marine technology —aquatic nuisance species—Part 2—ballast water sample collection and handling; and ISO 3725 ships and marine technology—ballast water sampling—verification testing protocol for compliance monitoring devices (IMO 2019a, 2021a).

The G2 Guidelines also provide further legal elements in support of the PSCOs work and professional judgement aiming at operatively clarifying the clear grounds legal concept for the BWM Convention purposes, which is supposed to trigger the passage from one inspection stage to the next by listing 12 cases (2.2.4).

Notwithstanding technical guidance provided through IMO cooperation and relevant efforts in simplifying PSC procedure, practical difficulties in fully implementing this important part of the BWM Convention still persists. Some Parties considered sampling as not essential while a valid IBWMC is on board, testifying a not in-depth understanding of the characteristics of the risks at stake (IMO 2016c). A different perspective emerges from organizations stressing the possible benefits for shipowners and/or crew members brought by indicative analysis instruments in monitoring BWMS performance prior to arrival in port to check normal BWMS operation or evaluate the effectiveness of a contingency measure implemented (IMO 2019c). Concerns on the technical difficulties of implementing PSC contributed to new technical proposals, e.g., self-monitoring devices continuously operating (IMO 2016b). It also has to be recalled that the differences in standards between the global regime and US regulations add technical burden for shipowners operating in more jurisdictions including the United States.

The BWM Convention assesses whether the treated organisms are viable or non-viable, and the sampling has therefore to determine whether they are capable of reproduction. However, according to the BWMS Code,

“viability may be established by assessing the presence of one or more essential characteristics of life, such as structural integrity, metabolism, reproduction, motility or response to stimuli” (IMO 2018c) thereby not requiring to test organisms for their reproduction potential.

It is worth mentioning that problems have been recorded on PSCOs actual available options when a discharge is found to be at risk or in case of emergencies. The availability of proper ballast water and sediments port reception facilities, on land or at sea, appears a sector that still needs to be fully explored by Parties and industry as a technical solution, in the absence of a correspondent obligation in the BWM Convention.

Finally, in parallel with the global implementation, existent coordination of PSC activities on a regional sea basis led to the update of relevant memorandums of understanding (i.e., Paris MoU 1982).

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4 Concluding Remarks

The review on the state of implementation and development of main provisions of the BWM Convention shows a lively treaty, in constant evolution. The production of Guidelines and technical guidance is quite common for shipping conventions developed within IMO. As outlined by its founding treaty, the Organization provides machinery for States’ cooperation on technical matters regarding ships and the prevention of marine pollution, ensuring in this process the full participation of main stakeholders. Technical developments and available solutions, new market technologies, uniformity of standards and relevant enforcement by flag, coastal and port States are issues commonly addressed during negotiations of IMO conventions as well as during their implementation. By addressing the prevention and control of marine pollution from ships, new requirements may provide inputs for new

market developments within the global industry concerned with maritime issues. IMO technical documents, i.e., codes, guidelines, circulars and resolutions play an important role both for implementation and for clarification purposes, each maintaining its respective legal value. For the BWM Convention as well as for other recent developments of other IMO conventions, e.g., MARPOL 73/78 Annex VI on air emissions from ships (MARPOL 73/78) or the Anti-fouling Convention (AFS Convention 2001), the development of technical guidance forms a core and essential part of the uniform implementation. Some stakeholders have argued that it would not be useful to agree on too many details at IMO, namely that there might be too many guidance documents. Nevertheless, this seems to be necessary when it comes to the implementation of the BWM Convention. The more details on implementation are provided by IMO, the more the States share a common understanding, easing a uniform practical application of the legal obligations. A uniform approach, even on quite detailed matters, may save time and efforts for stakeholders and facilitate Administrations in implementing the BWM Convention.

Threats posed by HAOP in ballast water and sediments are expanding along with the expansion of global trade and the increasing of ships' size, contributing to the damage of aquatic environments and economies, as well as posing risks for human health. Recent reviews of the methods for the calculation of costs of damage deriving from HAOP introduction showed very different results, stressing the risk of an under- or over-estimation of costs (Marbuah et al. 2014). On the other hand, the costs and burdens of implementation are high for the shipping industry as well as for Parties in their role of port and flag States. Uncertainties and complexities have not speeded up the implementation thus increasing the need of IMO technical guidance.

The BWM Convention is part of a legal evolution in which we are assisting to an increasing overlap between international environmental law, the law of the sea and related global maritime treaties. Environmental law is impacting on the development of maritime treaties and at the same time is affected by the States' practice within the IMO. Many uncertainties in the implementation as well as technical and technological shortcomings are a direct consequence of the need to integrate shipping technical matters with those of the marine environment. Straight examples of these inclusion of knowledge and concepts, until recent years and new to the world shipping community, are the quality requirements of the ballast water management standards, the regime for exemptions, ballast water sampling and the coastal and port States' duties on warnings. Other consequences of this integration are the enhancement of duties and burdens for port controls as well as of their powers and discretion. PSCOs, whose professional judgement needs nowadays to be supported by new technical expertise and tools, have increased their responsibilities. The new features are challenging traditional legal principles of the law of the sea (and of IMO conventions) such as the clear grounds, the delay of ships and even the entry into force conditions.

Soon the BWM Convention will become fully operational, while the need of the legal regime to adapt and evolve will not cease. The application to domestic voyages, the possibility to adopt more stringent measures, the risk assessment as an evidence-based uniform process supported by scientific reasoning, the need to address the efficacy of standards and their potential negative side effects might be in the future at the origin of further developments in the legal text and in the corpus of IMO resolutions and circulars as well as in international law.

The duty of States to cooperate, an already well-developed legal principle in shipping and environmental

matters, appears as a crucial element in future developments. Such cooperation (between ports, within and between regions) will have to address more and more frequently technical procedures and matters, i.e., common databases, common tools and common methodologies. In this regard, the capability of States of implementing the global standards on ballast water control and management would be facilitated, despite differences in legal application scopes, by the coexistence and coordinated implementation of different legal obligations aiming at pollution prevention and protection of the environment, of the human health and of economies.

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Footnotes

1 The terms "alien" and "non-indigenous" can be considered synonyms. However, in the text the term "non-indigenous" is preferred as the scientific wording agreed in the Working Group on Introductions and Transfers of Marine Organisms (WGITMO) of the International Council of the Exploration of the Sea (ICES), the expert group with the longest experience on the subject (https://www.ices.dk/community/groups/pages/wgitmo.aspx, last assessed

02.02.2023). Instead, in this chapter the term “alien” is used when mentioning a specific reference or legal text which makes use of such terminology.

© Springer Nature Switzerland AG 2024
M. David, S. Gollasch (eds.), *Global Maritime Transport and Ballast Water Management*, Invading Nature - Springer Series in Invasion Ecology 16
https://doi.org/10.1007/978-3-031-48193-2_11

Overall Conclusions on the Ballast Water Issue and Its Management Options

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Abstract
The Ballast Water Management (BWM) Convention entered into force in September 2018 to provide for a globally uniform approach in preventing harmful aquatic organisms and pathogens to further spread around the world by ballast water and sediment releases for the protection of natural environments, human health, property and resources, while at the same time considering the aspects of safe and efficient operations of shipping. As many times expressed before, the implementation of BWM measures has shown to be challenging at many different levels, from

technical to legal, which triggers constant needs for further continuous research and development of new technologies, methods, procedures, etc. After the first edition of this book was published in 2015 we continued with research efforts and work with BWMS producers and the shipping industry at the global level, as well as the cooperation at the Administration levels, which provided interesting insights and information resulting in this new edition. The updated state of knowledge is summarised here and presented thematically as per the book chapters. The main conclusions including some recognised issues, which are still to be solved in the future, are presented at the end.

Keywords Ballast water – Harmful aquatic organisms and pathogens – Invasive species – Ballast water management – BWM – Ballast water management systems testing – BWMS – Type approval – Final approval – GESAMP-BWWG – Ballast water sampling – Compliance monitoring and enforcement – Sediment management – Ballast water management in ports – Ballast water management convention

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1 Type Approval Tests of Ballast Water Management Systems, What We Have Learned in More Than 10 Years of Testing

At IMO it was concluded that the requirements outlined in the Guidelines G8 do not represent enough challenging test conditions to represent all waters where ballast water is taken up by vessels, hence they were amended to the Code for Approval of Ballast Water Management Systems (BWMS Code). Independently of IMO work, the United States Coast Guard established their own BWMS test

guidelines. Although the test guidelines are different, both requirements ended in a way that one Type Approval testing process may be conducted to satisfy the requirements of both.

With more challenging test requirements it is hoped that BWMS are tested at or near real world ballast water worst case uptake conditions so that the D-2 standard is met under a wide range of conditions. Additional and stronger test requirements are in the interest of all involved, including (a) the shipowner to have a better guarantee that the BWMS is fit for purpose, (b) the BWMS manufacturer to have a widely applicable BWMS and (c) the Administration to have greater confidence in the issued certificates.

It was noted that water conditions may still occur with, e.g., the content of Total Suspended Solids (TSS), even ten or more times higher than in the required land-based challenge water. However, these are considered as extreme events, which are unlikely to be handled by a BWMS routinely. Should BWMS fail under such conditions, contingency measures become relevant.

It is expected that the present test requirement amendments are expected to deliver better and more reliable BWMS test results to consequently have more reliable BWMS installed on vessels in the future. In turn this would result in better protection of the natural environment, human health and resources. In addition, this will help to avoid disruption of vessels' commercial activities in cases of failed compliance due to improperly performing BWMS.

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2 Testing Ballast Water Management Systems: Challenge Water Conditions During More Than 100 Test Voyages

This contribution summarised the intake water conditions observed during more than 300 samples taken during more than 100 shipboard BWMS performance tests during more than 12 years. The data presented include the abiotic water conditions (i.e., temperature, salinity, TSS and POC) and the counts of viable organisms in the two size classes addressed by the Ballast Water Performance Standard (Regulation D-2) of the BWM Convention.

Our data showed how close the G8 shipboard challenge water requirements are to what was observed in nature. In addition we compared our results with the test requirements of the US BWMS test protocol. Based on our results, further recommendations for G8/BWMS Code improvements were included. These recommendations refer to the challenge water conditions in performance tests of BWMS, which were kept unchanged during the recent G8 revision. One of our recommendations is to increase the required number of zooplankton organisms in the test water during shipboard tests to provide for a stronger challenge that BWMS meet the D-2 standard.

The results have shown also that the D-2 standard is unlikely achieved with unmanaged ballast water and ballast water exchange would in most cases also not result in the same level of protection as the D-2 standard. However, in ca. 10% of our samples the 10–50 µm organisms were already at uptake below the D-2 discharge standard. For both, phyto- and zooplankton, a much higher viable organism count was observed in freshwater, which makes BWMS tests here more challenging. Low viable zooplankton organism concentrations were observed in sampling events when larger water volumes were sampled. These larger sampling volumes may be a result of longer sampling times and higher flow rates so that these parameters may have an influence on organism survival.

Considering the abiotic parameters, it was recognised that the IMO Guidelines G8/BWMS Code TSS land-based

requirements (as expected to be the worst case scenarios) were never reached in freshwater conditions while even higher values of other parameters may occur in nature. Therefore, we do recommend to increase the TSS requirements for the land-based tests to ensure that BWMS are sufficiently challenged so that they can handle the water conditions in ports also under the challenging conditions that occur in nature. A similar situation occurs for POC values, which also seem to be set low to represent conditions in which vessel load ballast water to properly challenge BWMS during type approval tests. We therefore conclude that BWMS need to be tested more rigorously to increase the likeliness that they achieve the D-2 standard under a greater variety of naturally occurring port water conditions to allow widespread compliance with ballast water management standards.

The biological challenge water conditions for shipboard BWMS tests were almost always reached during shipboard tests for zooplankton, but in ca. 20% of the sampling events the phytoplankton requirement was not reached. Therefore, it seems that the challenge water standard for phytoplankton is stronger compared to the zooplankton requirement and we recommend increasing the zooplankton limit to bring both biological challenge water standards to a similar level.

IMO revised the Guidelines G8 and made them the BWMS Code without touching this aspect. However, IMO noted at the same time that more research results may provide evidence to re-negotiate certain aspects of this guideline/code and the BWM Convention. To generate knowledge, an experience building phase (EPB) was initiated by IMO to promote research in this field. The agreed EBP has three stages, i.e., data gathering (completed), data analysis (completed) and a review of BWM Convention and its supporting guidelines and guidance documents (to come). We hope that our results

will also be considered during EBP to justify certain changes in a future revision of the BWMS Code.

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3 Ballast Water Discharges and Safety Aspects of Using Active Substances for Ballast Water Treatment

BWMS using active substances (AS) for ballast water disinfection need to undergo a testing process as required in the IMO BWMS Code and Procedure (G9). Due to the application of AS in the BWMS disinfection by-products (DBPs) may be produced. Therefore, a technical working group was formed to ensure that the AS discharge and DBPs remain below predefined acceptable limits with the aim to protect the environment, crew and ship against any possible side effects of the BWMS treatment. Accordingly, a risk assessment (RA) methodology was developed by the Ballast Water Working Group of the UN Joint Group of Experts on the Scientific Aspects of Marine Environment Protection (GESAMP-BWWG). This methodology was based on internationally accepted RA procedures. The RA deals with (a) the potential risks for the environment due to the direct discharge and (b) for human health due to potential direct exposure of the vessel crew or port State control officers (PSCOs) when conducting their regular work onboard, or due to an indirect exposure of the general public by swimming in areas or nearby where ballast water is released or by eating contaminated seafood. In case the RA shows that the ballast water treatment may cause a risk to the environment, the workers onboard, or the general public, such BWMS should not receive an approval recommendation by GESAMP-BWWG. However, the final decision about the acceptability of a BWMS, and thereby,

the allowance to market a BWMS, is taken by the Marine Environmental Protection Committee of IMO and is based on the recommendations of GESAMP-BWWG.

Like all regulatory RA schemes for chemicals, the GESAMP-BWWG Methodology has the challenge to simplify a multitude of separate situations in a way that they can be reflected by a limited number of calculations. Otherwise, RA would be impossible. In this process, assumptions and estimations have to be made, which may be debatable. GESAMP-BWWG frequently re-evaluates its own Methodology, taking into account the latest available research and evidence. In case the Group considers it well justified, the standard assumptions in the Methodology will be changed or complemented by additional considerations and explanations. This is evidenced as IMO has recently published already the fifth revision of the original Methodology.

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4 Compliance Monitoring and Enforcement of the BWM Convention: The Port State Control Perspective

One of the very critical aspects for an effective implementation of the BWM Convention is the Compliance Monitoring and Enforcement (CME) process. The BWM Convention provides basic requirements regarding inspections and consequences, while this process is further supported by the IMO Port Sate Control (PSC) Guidelines and IMO G2 Guidelines on ballast water sampling (BWS). As the G2 Guidelines were recognised to lack details, further Guidance for BWS was prepared. Regional approaches under memoranda for PSC also started to develop. Latest research is showing that there are still uncertainties, issues and unconformities what could penalise international shipping and on the other side it may

weaken the BWM Convention implementation. CME under the BWM Convention was also recognised to be rather specific, introducing different principles and approaches than other IMO Conventions, what makes it even more challenging for PSC officers.

The BWM Convention implementation essentially requires the cooperation of parties globally and regionally, especially in situations where several jurisdictions are located along a regional sea. Here, a harmonised CME application approach is supporting the avoidance of confusions regarding which a jurisdiction requires a certain approach. Also, the approach chosen may be different than in a neighbouring jurisdiction, which is especially critical to avoid additional burden on shipping and to provide for more effective implementation of BWM Convention measures.

Inspections organised under different regional agreements, MoUs, further detail/organise the process to their specifics. From an analysis of the reports submitted to the MEPC sub-committee on Implementation of IMO Instruments (III) at IMO from the MoUs on PSC, ballast water inspections seem to be under-reported for the Paris and Tokyo MoUs. The rest of the MoU’s reports show significantly less than the Paris/Tokyo MoUs and a number of the smaller ones from developing countries do not even list ballast water as something they inspect.

The guidance on methodologies is there, but the reality of how the Member States who have ratified the Convention operate is completely different. Many countries satisfy their national legislative requirement in a very minimal way. That is an initial inspection of the paperwork, certificates, plan and record book. If all is in order, then the inspector moves on. Other countries are more deliberate in their activities. They will conduct an indicative sample (generally in a narrow organism size search range) and have the ability to ramp-up to full.

When implementing CME process one of the critical steps becomes the vessel selection for inspection. This seems to be still a very much overlooked process in terms of having inspection triggering points related to the ballast water risk level. Actually, to our knowledge, none of the MoUs at present has taken up ballast water-related triggering elements. Consequently, vessels are still selected for inspection based on ship safety elements, which does not tell much/anything about the risk of the ballast water to be discharged, which is a crucial element targeted by the BWM Convention. Meaning, if there is no risk there is no need for protective measures, and the opposite. To this end different studies were conducted and RA models were developed to support such processes. These could best be implemented through regional/MoU approach as part of a BWM Decision Support System.

Considering the information received from the IMO Experience Building Phase, CME inspections are today mainly limited to documentation checks and crew familiarisation with essential shipboard BWM procedures including their implementation. This means that BWS as inspection tool provided by the BWM Convention is not being used. It is important to note that BWS is actually the only way to verify biological performance against the D-2 standard as the BWMS monitoring tools do not have this capacity. This is also confirmed through the experience with Commissioning Testing according to BWM Circ.70. Rev.1, where almost all BWMS that failed in biological performance, their monitoring equipment did not show an irregularity. Representative BWS is not so trivial and detailed analyses also require certain level of education and laboratory capacity, which is not available at responsible authorities that conduct PSC, which may be a reason that this is not yet being conducted. However, at present there are different certified laboratories that regularly conduct such tests for the purpose of Type

Approval and Commissioning Testing, and these could be also used for CME purposes.

Based on the Experience Building Phase results, IMO is currently working on a Convention Review Plan, which also will consider associated guidelines and guidance documents. The BWM Convention review stage is expected to develop amendments through a systematic and evidence-based approach and ensure that amendments are developed holistically, taking into account any inconsistencies or ambiguities, through an objective, transparent and inclusive approach. The review may also consider any further information or data submitted to the Committee and as such interested parties are encouraged to collect and submit such information.

In conclusion we believe it is never enough strongly stated how important it is to implement the BWM Convention at the regional scales, and the MoUs are well established control systems to support the effective implementation of international instruments in the shipping industry. Unfortunately, none by now have adequately considered this. Hence, we would strongly recommend to take this initiative for the sake of the shipping industry and the environmental protection.

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5 Ballast Water Sampling for Compliance Monitoring and Enforcement of the BWM Convention: D-1 and D-2 Indicative Tests

In accordance with the BWM Convention vessels may be subject to inspections for the purpose of revealing violations of convention provisions, and sampling of ballast water for subsequent analyses makes part of such inspections. The reliability of compliance tests is of critical

importance, since the consequences of failing compliance with the required standards may result in vessels being banned from discharging ballast water, which may result in the inability of completing cargo operations. Regulations D-1 and D-2 indicative sampling and analysis methods were tested on commercial vessels during voyages, and on vessels calling to Slovenian and Italian ports. Sampling at different depths along the in-tank water column evidenced a heterogeneous distribution of physico-chemical parameters, i.e., salinity, temperature, pH and oxygen content, and viable phytoplankton. The highest phytoplankton abundance was observed in bottom samples. Very high phytoplankton abundances of organism <10 µm were observed compared to organisms 10–50 µm.

Considering this, compliance control sampling becomes a challenging task to take a representative sample, and at least two samples taken would be recommended. However, it was not yet clarified which organism concentration value will be used for CME purposes, the lowest, the highest or the mean value, and it is recommended to use the mean value of all measurements of a single tank to avoid a biased compliance assessment, i.e., not to base a compliance conclusions on an under- or oversampled organism abundance.

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6 Ballast Water Management Options in Ports

The BWM Convention requires that vessels discharge ballast water according to its requirements. This means that vessels are obliged to properly manage the ballast water to be discharged. However, due to different reasons, improper ballast water may occur. The reasons for this may be numerous but commonly include technical BWMS failures or bad weather conditions. In such cases the BWM

Convention requires port State authorities not to permit ballast water discharges and to offer an adequate alternative management option. By now, different alternative BWM options are considered in the relevant literature, but some were also examined in practice. Although technologies for these alternative management options are almost identical to those implemented onboard merchant ships, they are significantly different in the necessary conditions, requirements and business models when comparing onboard solutions with port-based BWM options.

Port-based solutions considered so far include land-based, barge-based and mobile truck-based BWMS with all using practically identical treatment technologies commonly which are used onboard ships. As almost always, each solution considered has certain advantages and disadvantages, which are more or less emphasised in accordance with the port configuration, traffic volumes, required ballast water capacities, etc.

Nevertheless, currently two main disadvantages prevent the wider use of these port-based solutions. The first disadvantage is of technical nature: most ships lack arrangements to discharge ballast water to a port-based ballast water reception facility, thereby significantly reducing the feasibility of port-based solutions. Also, there is no standardised technical connection between the ship and such a facility. To overcome this problem we recommend that such a standardised connection be urgently agreed with the aim to enable the further development and use of such reception facilities. The second disadvantage is related to the economic viability of such a facility, which is due to the (currently) limited demand and relatively high capital and operational costs, making the profitability of such a service uncertain.

Because of these characteristics, the decision to implement a port-based system is recommended to be

based on a thorough data analysis and modelling of port dynamics, to preferably estimate the system's efficiency in different circumstances using simulations. For ports without ballast water reception facilities, the responsible authorities have to consider other contingency measures to manage non-compliant ballast water.

Not in the least, decision-makers should consider in their plans that using port-based BWMS may minimise the introduction risk of harmful aquatic organisms and pathogens compared to the "do nothing" option when an onboard BWMS fails.

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7 Ballast Tank Sediment: A Neglected Subject Which Requires Management

Sediment releases from ballast tanks are of concern to the environment as they may contain chemical contaminants and living organisms accumulated since the last docking visit of the vessel. This is one of the reasons why the BWM Convention also addresses sediment. IMO further developed guidelines for sediment reception facilities (Guidelines G1) and adopted Guidelines G12 to minimise the uptake and undesirable entrapment of sediments, to facilitate removal of sediments and provide safe access to allow for sediment removal. In essence, when a port State offers services where sediment is removed from the tanks, adequate facilities for the reception of sediments should be provided in ports and terminals where the cleaning and repairing of ballast tanks occur. Further, each State shall report to IMO on the availability and location of any reception facilities for the environmentally safe disposal of sediments. In addition, the BWM Convention gives detailed requirements for sediment management for vessels. This means that vessels shall remove and dispose sediments from ballast tanks according to their Ballast Water

Management Plans in which detailed procedures for the disposal of sediments on shore shall be provided. With this, appropriate sediment collection and disposal in shipyards and ports become now a new challenge.

The amount of the ballast tank sediments a port or shipyard may receive in a year is largely unclear. It was observed that importance of sediment management is not fully understood, but that instruments have to be developed to harmonise procedures and requirements for temporary and/or permanent sediment reception facilities. Hence, when working towards appropriate sediment management in accordance with IMO requirements, a more detailed study of sediment discharge profiles in a dockyard (e.g., maximum volume per vessel, annual volume of sediment discharge to reception facilities) would be needed to estimate the capacity of such facilities.

With the BWM Convention in force, each State has to report to IMO on the availability and location of any reception facilities for the environmentally safe disposal of sediments. Further, as per the BWM Convention, detailed ballast water management plans need to be developed in which detailed procedures for the disposal of sediments on shore shall be provided. It would be also helpful for the shipping industry, and possibly also researchers, when IMO would make publicly available the collected information on existing sediment reception facilities, e.g., through GISIS (Global Integrated Shipping Information System).

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8 Databases to Support Different Ballast Water Management Tools

BWM is a complex process in which decision-making must be based on proven scientific evidence. For example, data is needed to make decisions on the granting of exemptions from BWM, to support an early warning system to inform

seafarers about where ballasting should not be conducted due to the presence of harmful organisms, to control and eradicate invasive species and to measure the effectiveness of the BWM Convention in reducing the rate of new species introductions. To support different BWM tools, the data should be diverse and multifaceted, ranging from taxonomy and biological traits of introduced species to the limits of their ecological tolerance, vectors of introduction, history of invasions and actual geographic distribution, their impact on human health, economy and environment.

The only way to promptly provide the needed data is to create, maintain and constantly update centralised databases such as AquaNIS. Such an information system should be multifunctional, based on the principle of “collect data once, use it many times,” so that the accumulation of data allows not only their operational use to meet urgent needs for decision-making, but also for analysis and forecasting. For the purposes of the BWM Convention, it is also important that such database contains information not only on introduced species, but also on local harmful organisms and pathogens which can be transferred with ballast water.

Finally, the information system must have institutional support at the level of regional or, better, global organisations and conventions, so as not to depend solely on the enthusiasm of its developers and data providers.

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9 Five Years of “Lively” Implementation of the BWM Convention: Global Guidance, Regional Challenges and National Issues

The review of the implementation state and the development of main BWM Convention provisions show that this is a lively treaty with a need for constant evolution. As for other shipping conventions the production of Guidelines and technical guidance is quite common within IMO. Already in its founding treaty, the organisation provides measures for States' cooperation not only on technical matters regarding ships and the prevention of marine pollution, but also ensuring the full participation of main stakeholders in this process. Other aspects, including technical developments and available solutions, new market technologies, uniformity of standards and relevant flag, coastal and port States enforcements are issues commonly addressed during negotiations of IMO conventions and also during their implementation.

In case of the BWM Convention technical guidance forms a core and essential part of its uniform implementation. However, some stakeholders argued that it would not be needed to agree on too many details at IMO, as this may result in too many guidance documents. Nevertheless, guidance seems to be necessary for the BWM Convention implementation as the more details are provided by IMO, the more the States share a common understanding, which eases a uniform practical application of the legal obligations.

The BWM Convention is part of a legal succession with an increasing overlap of international environmental law with the law of the sea and related global maritime treaties. Notably, environmental law is impacted by maritime treaties developments and is also affected by the States' practice within IMO. Many implementation uncertainties and technical as well as technological shortcomings are a direct consequence of the need to integrate shipping-related technical matters with those of the aquatic environment. Examples of these knowledge and concept inclusions, until recent years and new to the global

shipping community, are the quality requirements in the BWM standards, the regime for exemptions, ballast water sampling, and further the coastal and port States' duties on warnings. Other consequences are the enhancement of duties and burdens for PSCOs as well as of their powers and discretion. PSCO, whose professional judgement skills nowadays need to be supported by new technical expertise and tools, thereby have increased their responsibilities. These new features challenge traditional legal principles of the law of the sea (and of IMO conventions), including the clear grounds principle, the delay of ships and even the entry into force conditions.

The BWM Convention will soon become fully operational. At the same time the need of the legal regime to adapt and evolve will not cease. Further developments in the legal text via IMO resolutions and circulars as well as in international law may have to address the application of the BWM Convention principles to domestic voyages, the option to adopt more stringent measures, the risk assessment as an evidence-based uniform process supported by scientific knowledge and the need to address the efficacy of standards and their potential negative side effects.

Further, the States' cooperation (between ports, within and between regions), which is an already well-developed legal principle for shipping and environmental matters, appears here as a crucial element for future developments. This cooperation may also address more and more frequently technical procedures and matters, including, common databases, tools and methodologies. In this regard, the capability of States in implementing global ballast water control and management standards would be facilitated, despite legal application scope differences, by the coexistence and coordinated implementation of different legal obligations aiming at pollution prevention,

protection of the environment, human health and economies.

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10 Final Conclusions

After all the scientific research, shipping and BWMS industry, as well as Administration efforts in supporting an efficient BWM Convention implementation, it is very clear that there are still different (several) issues to be solved. From all those pointed out by this book and elsewhere, we would from our direct experience in this field point out the following as the most critical:

- Vessel crews have difficulties to operate BWMS in more challenging water conditions, especially where there are high sediment and organisms loads. BWMS Type Approval tests would need to get even more robust as it became clear that the conditions in which BWMS are being tested do not reflect well the water conditions in which vessels then have to use BWMS. As a consequence, current discussions at IMO include BWM in ports with challenging water conditions.
- There may be different issues/failures in BWMS and vessel ballast system which lead to improper/ineffective ballast water treatment, but these are not recognised by BWMS or vessel control systems as there is no control system on BWMS or vessel to measure the organism's presence and viability during the discharge. Failures include, e.g., when BWMS bypass valve fails to close 100% and this is not recognised by sensors so that organisms bypass BWMS during uptake and the most resistant survive also during the discharge; when BWMS filter would fail (hole in mesh etc.), larger organisms also would pass through which then are not successfully treated by other methods (e.g., UV, active substance) used; when the valve separating the ballast water intake

from the sea chests and the line from the ballast tanks do not close 100% then untreated water is mixed with the treated during the discharge, which does not represent a biological problem, but would make the vessel fail on a D-2 standard compliance test. At present these issues are being regularly identified (and rectified) during BWMS Commissioning Testings, which are required by IMO for all BWMS first installations from 1 June 2022. However, once the International BWM Certificate is issued, there are no further requirements for such checks during annual, intermediate or renewal surveys, hence we strongly recommend that BWMS biological performance testing is introduced also during future class surveys, i.e., not only during the initial survey, but also during the intermediate and the renewal surveys (if not also during annual ones e.g., for older vessels which have more deteriorated valves).

– Ballast water samples for the purpose of Commissioning Testing may be analysed in an indicative manner, with an indicative tool, i.e., Compliance Monitoring Device (CMD). This way the testing becomes more practical so that a technician may do it, but at the same time it becomes also inaccurate, possibly unreliable. CMDs being used for these tests worldwide were all developed relatively recently and did not undergo any standardised testing for their performance. Since July 2023 testing procedures for CMDs are in place (IMO BWM.2/Circ.78). To achieve the main goal for which the Commissioning Testing was actually introduced, i.e., verify the biological performance of the BWMS at its installation on the vessel, we would recommend detailed analyses to be used, practically using the same methods and approaches as were used during the BWMS Type Approval tests.
– There are practically very little CME activities undertaken at this point globally. Port and flag State inspections would need to become regular and would

need to involve ballast water sampling capacity to prove that the biological performance of BWMS is adequate. Vessel crews are well aware of this.

– Although the BWM Convention emphasises importance of regional cooperations, there is still little done or effective on this globally. We believe it is never enough strongly stated how important it is to implement the BWM Convention at regional scales, and MoUs are well established control systems to support the effective implementation of international instruments and as much as possible avoid additional burden to the shipping industry.

As with the first edition of this book, we show here how complex ballast water management is and that experts of many disciplines are essentially needed for the proper implementation of the BWM Convention. One way of documenting this complexity is to recall that it took almost 50 years to address this problem at IMO after mentioning species introductions by ballast water at IMO first (in 1973). In a succession of efforts, BWM guidelines were developed first followed by the BWM Convention, which was adopted with a large number of supporting documents and it eventually entered into force in September 2017.

With this convention now in force and as the D-2 standard applies from September 2024 to almost all ships, we hope that the number of newly arriving harmful aquatic organisms and pathogens will considerably be reduced so that the overall convention objective becomes reality, which is to eliminate the risks to the environment, human health, property and resources arising from the transfer of such organisms with ballast water and sediments.

Knowing that shipping is not the only vector to unintentionally move species around the globe, we hope that other until now unregulated pathways of species introductions will also soon be regulated for an even better

protection of the aquatic world and all depending on or being otherwise related to it.